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13. ABSTRACT *(Maximum 200 words)*
The Joint Service Lightweight Integrated Suit Technology (JSLIST) Program, defined in a 1993 Memorandum of Agreement signed by representatives of the U.S. Marines, Army, Navy, and Air Force, is responsible for overseeing development, production, and deployment of the next generation of chemical/biological protective suits. This report is of two human studies conducted to: (1) address the services requirement for new garments that impose less heat stress than current protective garments, and (2) provide data for the Health Hazard Assessment. The suits tested included overgarments, undergarment and duty uniform concepts. The field study was conducted at Yuma Proving Ground, AZ in the summer of 1995, and a controlled environmental chamber study was conducted in the summer of 1996 at the United States Army Research Institute of Environmental Medicine and the United States Navy Clothing and Textile Research Facility, Natick, MA. Physiological measures were made of rectal temperature, skin temperature, heart rate, sweating rate, and test time; while questionnaires evaluated subjective symptoms of heat illness. The results of the field and chamber studies indicate that the Army's Battledress Overgarment imposes the most heat strain, the Marine Saratoga and Navy Chemical Protective Overgarment impose the least, and the JSLIST prototype garments imposed heat strain that ranged between the worst and best controls.

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TECHNICAL REPORT

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Joint Service Lightweight Integrated Suit Technology Program
Heat Strain Evaluation
in an Environmental Chamber and in the Field

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ACKNOWLEDGMENTS

As its name implies, the planning and completion of the Joint Service Lightweight Integrated Suit Technology (JSLIST) Program's heat strain evaluations in the field and in the environmental chamber included input from the U.S. Army, Navy, Air Force and Marine Corps. The authors would especially like to acknowledge the contribution of the Marines and the Soldiers who volunteered to participate as test subjects. They played an invaluable role in making these studies successful. The field study was conducted as a joint effort by the U.S. Army Research Institute of Environmental Medicine (USARIEM), U.S. Navy Clothing and Textile Research Facility (USNCTRF), U. S. Naval Health Research Center (USNHRC), and representatives from the U.S. Air Force (from Brooks Air Force Base, TX, and Kirtland Air Force Base, NM) and U.S. Marine Corps including CWO Joe Threat, SSGT Flanagan and SSGT MaCauley (from Twentynine Palms and Camp Pendleton, CA). Our hosts for the field study were the civilians and soldiers from Yuma Proving Ground, especially Mr. Tom Sargent and the staff at the medical clinic. The chamber study was conducted as a joint effort by USARIEM and USNCTRF, with many of the test subjects volunteering from the U.S. Marine Corps at the California bases. At USNHRC, Mr. Ross Vickers and Dr. Don Roberts helped with the data reduction. At USNCTRF the authors would especially like to thank Mr. Joe Giblo for providing excellent climate control for the test chamber, and Mr. Mike Salem for the acquisition and daily coordination of all the test garments and accessories. At USARIEM the authors would like to thank Bob Wallace for the statistical analyses, SGT James Kain and Mr. Gerry Newcomb for overseeing organization, shipment and set-up of our equipment and for taking care of the visiting test volunteers, and the student interns: Martin LeQuesne, Christine McClellan, Jeff Griewe, Dan McCook, Kyle Spear, Cheryl Durr-Patry, and Marissa Volpe, who helped out in one or more phases of testing and data reduction.

LIST OF ACRONYMS

ANOVA	Analysis of Variance
ARIEM	U.S. Army Research Institute of Environmental Medicine
BDO	Battledress Overgarment
BVO	Black Vinyl Overboot
CB	Chemical Biological
CHPPM	U.S. Army Center for Health Performance and Preventive Medicine
CPO	Chemical Protective Overgarment
CPU	Chemical Protective Undergarment
CVC	Combat Vehicle Crewman Coverall
D	Duty Uniform
DFR	Fire Retardant Duty Uniform
DNFR	Non Fire Retardant Duty Uniform
FR	Fire Retardant
GHP	Guarded Hot Plate
GVO	Green Vinyl Overboot
ISO	International Standards Organization
HHA	Health Hazard Assessment
ICPG	Improved Chemical Protective Glove
JSLIST	Joint Service Lightweight Integrated Suit Technology
MOA	Memorandum of Agreement
MOPP	Mission Oriented Protective Posture
MULO	Multi-Purpose Overboot
NCTRF	U.S. Navy Clothing and Textile Research Facility
NFR	Non Fire Retardant
NRDEC	U.S. Army Natick Research, Development and Engineering Center
O	Overgarment
OFR	Fire Retardant Overgarment
ONFR	Non Fire Retardant Overgarment
POMS	Profile of Mood States
RH	Relative Humidity
SAR	Saratoga
SHI	Subjective Heat Illness

TBDU	Temperate Battledress Uniform
USMC	U.S. Marine Corps
VPFRU	Vapor Protective Fire Retardant Undergarment
YPG	U.S. Army Yuma Proving Ground
YSI	Yellow Springs Instruments

EXECUTIVE SUMMARY

The Joint Service Lightweight Integrated Suit Technology (JSLIST) Program (originally a U.S.Marine program) was defined in a 1993 Memorandum of Agreement signed by representatives of the U.S. Marines, Army, Navy, and Air Force. The responsibilities of the JSLIST Program are to oversee development, production, and deployment of the next generation of chemical/biological protective suits for service men and women. This report is of two human studies conducted to: 1. address the services requirement for new garments that impose less heat stress compared to current protective garments, and 2. provide data for the Health Hazard Assessment (conducted by the U.S. Army Center for Health Performance and Preventive Medicine). The suits tested included overgarments (5 prototype fabrics in one design vs 3 currently fielded garments as controls, and 1 fabric in another prototype design vs one of the controls), undergarment (1 prototype vs 1 control) and duty uniform (1 prototype vs 1 control) concepts designed to be compatible with existing and prototype protective equipment. The field study (21 subjects [17 male, 4 female] tested 13 garments) was conducted at Yuma Proving Ground, AZ in the summer of 1995 and a controlled environmental chamber study (12 subjects [10 male, 2 female] tested 14 garments) was conducted in the summer of 1996 at the United States Army Research Institute of Environmental Medicine and the United States Navy Clothing and Textile Research Facility, Natick MA. Physiological measures were made of rectal temperature, skin temperature, heart rate, sweating rate, and test time; while questionnaires evaluated subjective symptoms of heat illness. The results of the field and chamber studies indicate that the Army's Battledress Overgarment imposes the most heat strain, the Marine Saratoga and Navy Chemical Protective Overgarment impose the least, and the JSLIST prototype garments imposed heat strain that ranged between the worst and best controls.

INTRODUCTION

The Joint Service Lightweight Integrated Suit Technology (JSLIST) Program seeks to develop a chemical and biological (CB) protective ensemble, for use by all Services, with an improved design providing better chemical protection and reduced heat strain compared to current ensembles. In 1993, a Memorandum of Agreement was signed by representatives of the U.S. Marines, Army, Navy, and Air Force. This memorandum defines the JSLIST program and the responsibilities of the participant organizations for the development, production, and deployment, of the next generation of CB protective suits. The new garments are designed to replace the current standards. The current standards are, for the Army and Air Force: the Battledress Overgarment (BDO); for the Marines: the Saratoga (SAR); and for the Navy: the Chemical Protective Overgarment (CPO). In keeping with the attempt to continually improve upon the currently fielded ensembles, the JSLIST program has overseen the process of testing prototype suits which met services' requirements for dismounted ground forces, armored vehicle crews, shipboard crews, rotary wing aviation crews, and service and support personnel. These suits include overgarment, undergarment and duty uniform concepts for CB threats. They are to be compatible with existing and prototype protective equipment (gloves, boots, masks) to complete the Mission Oriented Protective Posture (MOPP). The JSLIST ensembles are suitable for wear in all weather conditions and combat situations with minimal impact on combat effectiveness. The garments are designed to be worn with or without a duty uniform and/or cold weather gear, and are designed to be compatible with currently fielded equipment, e.g. body armor and load bearing equipment.

All Heat Stress Testing for the JSLIST program was specified in the JSLIST Test Operating Procedure for Heat Stress Testing of Protective Clothing Materials and Ensembles, 21 February 1996 (most recent update at the time the study protocol for the chamber study was written). This report is of two human studies designed to address the issue of heat stress. The first was a field test, conducted (summer 1995) at Yuma Proving Ground (YPG), Yuma, Arizona. The second was an environmental chamber test, conducted (summer 1996) at the United States Army Research Institute of Environmental Medicine (USARIEM) and the United States Navy Clothing and Textile Research Facility (NCTRF) both in Natick, Massachusetts. Prior to any human heat stress tests, biophysical tests were performed, including guarded hot plate (GHP), thermal manikin, and prediction modeling. The GHP tests provided information on the thermal resistance (insulation) and

water vapor resistance (permeability) for the textile swatch tested (International Standards Organization, 1993; Endrusick, 1993). Manikin tests provided information on the same thermal characteristics for the constructed garment, accounting for garment drape and air layered inside the garment (Breckenridge, 1977; Gonzalez et al, 1993). Prediction modeling of themoregulatory responses provided information on predicted core temperatures, maximum endurance times, optimal work/rest cycles, and water requirements (Gonzalez et al, 1993; Gonzalez and Stroschein, 1991; Pandolf et al, 1986). Based on selection criteria provided by the four Services (including GHP and chemical agent testing as well as physical properties testing such as fire retardancy and durability), the 5 best fabric candidates (of 53 considered) were selected to go forward in the garment development process. All 5 candidates were included in these studies since all 5 were to be considered for type classification so that the Services would be at the advantage of being able to consider other acquisition factors (such as cost and availability) in addition to heat stress and chemical protection factors. Since human tests are by nature limited to relatively few conditions, these studies were comprised of a matrix of tests which addressed the main requirements for each service. In the chamber study, a matrix of 14, and in the YPG study, a matrix of 13, prototype and control garments were tested for heat stress using volunteer Soldiers and Marines (Tables 1 and 2).

The BDO, or a very similar counterpart, has been used for more than 20 years during military operations which require military personnel to wear CB protective clothing. The BDO, used as a control in each of these studies, is heavy, bulky, relatively impermeable to water vapor, and has a high insulation value. It thus limits dry and evaporative heat exchange between the wearer and the environment, adds to the metabolic cost of work performed, and generally exacerbates any existing heat stress. The heat stress problems associated with wearing the BDO are well documented (Goldman, 1963; Henane et al, 1979; Joy and Goldman, 1968). The original Saratoga design was shown to be better in terms of heat stress than the BDO, but comparisons of the currently fielded Saratoga design (more fabric added to heighten the back of the trousers for better jacket-to-trousers protection) indicated that the original advantages over the BDO were somewhat diminished, especially at hotter temperatures and heavier work intensities. (personal communication with Dr. William Santee and Mr. Clement Levell and references: Gonzalez et al, 1994; Santee et al, 1993). The currently fielded Saratoga design was also used as a control in each of these studies. The Navy CPO (used as a control in the chamber study), a two piece CB protective garment (trousers and smock with integral hood), has also been

shown to impose less heat stress on the wearer compared to the BDO (Gonzalez et al, 1989). The chemical protective undergarment (CPU, used as a control in each of these studies) has been shown to impose significantly less heat stress than the BDO, when each is worn with a duty uniform, although the CPU benefit becomes non-significant when the BDO is worn over personal underwear only (Levine et al, 1993). The CPU and the prototype JSLIST Vapor Protective Fire Retardant Undergarment (VPFRU) are made from the same fabric. The CPU and VPFRU are designed to be worn under a duty uniform (the combat vehicle coverall [CVC] in these studies). The VPFRU is made in a prototype design, with an integral hood instead of the butyl hood used with the CPU.

PURPOSE

The purpose of the chamber study was to evaluate and compare physiologic heat strain while volunteers wore prototype and control garments and performed controlled exercise in an environmentally controlled test chamber. The comparisons were designed to show if any of the prototype garments elicited significantly less heat strain than the controls. The purpose of the field test was to evaluate physiologic heat strain during a somewhat realistic exercise, while volunteers wore prototype and control garments and performed a simulated chemical-biological reconnaissance (walking pace and stops were controlled) in a desert environment. In addition to the results of the chamber study, these evaluations would provide garment users and assessors an idea of how the prototype garments compared to the controls with respect to tolerability in the heat, and provide heat strain information to supplement the findings of the wear tests. These chamber and field studies are important to the U.S. Marines, Army, Navy, and Air Force, as they address concerns about the possible health hazard of heat stress in the JSLIST prototype CB protective garments. This issue must be addressed by the U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM), in their evaluation and the Health Hazard Assessment (HHA) report to the Surgeon General. The HHA report is a requirement prior to materiel acquisition by the Army. This comparison of the garments is also necessary for input to the down selection process (coordinated by the U.S. Army Test and Evaluation Command), and provides down selection and acquisition information to the User communities in the four Services. In addition to the physiological evaluations, these studies also addressed subjective aspects of heat strain for the purpose of evaluating the test garments relative to the volunteers subjective responses. Along with results from the operational and other

developmental tests, the results from these studies have been assessed by representatives from the Services in their attempt to select one or more of the tested garments for future use by military personnel.

GARMENTS

The JSLIST garments have been designed for CB protection and for use in all weather and combat situations. Specific designs and/or fabrics may be worn as undergarments (in a layer under the duty uniform), primary duty uniforms, overgarments (in a layer over the duty uniform), or over/under cold weather garments, depending on the mission, the CB threat, and the environment. The ensembles are encapsulating semipermeable two piece-suits. JSLIST prototypes (except the aviation garment tested in field study), and the CPO and SAR controls have integral hoods. The ensembles include gloves, overboots, and protective mask. The JSLIST garments are designed to be compatible with current use duty uniforms and protective masks, and with current use and prototype overboots and gloves. When the CB overgarments were worn over a duty uniform, the standard Temperate Battle Dress Uniform (TBDU) was used. A JSLIST prototype overboot (MULO, multi-purpose overboot) and glove (ICPG, improved chemical protective glove) were used by half the volunteers in the field study (in all of their trials), half used the standard green or black vinyl overboots (GVO or BVO) and gloves (butyl rubber with cotton liners). Because the overboot and gloves were not expected to differ with regard to overall heat stress, they were not compared, but were included to provide additional wear data for the JSLIST program. In the chamber study, the prototype MULO and ICPG were used during the JSLIST garment trials, and the standard GVO or BVO and gloves were used in the control trials (except no overboots for CPU and VPFRU trials). Again, no attempt was made to compare the boots and gloves separately from the whole ensemble. The CPU was worn with combat boots and standard issue socks; the VPFRU was worn with combat boots and standard socks in the field study and with combat boots and chemical protective socks for the chamber study. (Because the chemical protective sock added a layer inside the boot, only 7 of 12 volunteers in the chamber study could wear them. Volunteers wore their own (broken-in) combat boots during all trials in these studies.) Both undergarments were worn under the Combat Vehicle Crewman Coveralls (CVC).

Except for the CPU and VPFRU, the JSLIST and control fabrics were two-layer, carbon technology liners with shells. The shell fabrics were made of either triblend of cotton/para-aramid/nylon (FR and NFR JSLIST fabrics), nylon/cotton (NFR JSLIST fabrics and BDO), cotton (FR and NFR JSLIST fabrics and SAR), or mod-acrylic/nylon (CPO). The CPU and VPFRU were made from a single layer carbon non-woven fabric. The weight of the garments (including the duty uniform and t-shirt but not underpants/shorts) and overboots, gloves, mask and instrumentation was approximately 6-9.5 kg (~13-21 lbs) for the chamber study. For the field study, the addition of two (full) 1-liter canteens, the pistol belt, helmet, and datalogger added approximately 6 kg for total garment and instrumentation weights of 12-15.5 kg (~26-34 lbs). See Tables 1 and 2 for the listing of garments tested in the chamber and field studies.

Table 1. GARMENT TRIALS - CHAMBER STUDY

GARMENT TRIALS	DUTY UNIFORM	MASK/ HOOD	BOOT/ GLOVE	ENVIRON-MENT
1. JSLIST-OFR 1	TBDU	M40 /integral hood	MULO/ ICPG	95°F(35°C) 50%rh
2. OFR 2	TBDU	"	"	"
3. ONFR 1	TBDU	"	"	"
4. ONFR 2	TBDU	"	"	"
5. ONFR 3	TBDU	"	"	"
6. SAR-CONTROL	TBDU	"	G-BVO/ butyl	"
7. BDO-CONTROL	TBDU	" /butyl hood	"	"
8. CPO-CONTROL	TBDU	"/integral hood	"	"
9. ONFR 3*	NONE	"/integral hood	MULO/ICPG	"
10. VPFRU	CVC	M40** /integral hood	combat boot, sock/ICPG	"
11. CPU-CONTROL	CVC	" /butyl hood	combat boot/ butyl	"
12. DNFR 2 *	NONE	MCU2P** /integral hood	MULO/ ICPG	"
13. DNFR 2 *	NONE	"	"	75°F(24°C)/50%rh
14. BDO-CONTROL	NONE	" /butyl hood	G-BVO/butyl	"

* Trial 9: Worst case JSLIST Overgarment (O) used in this study was ONFR3 (based on manikin testing).
* Trials 12,13: Worst case JSLIST Duty Uniform (D) used in this study was NFR2 (based on manikin testing). At YPG the worst case fabric used was NFR1 (based on GHP results); but based on YPG test results, the worst case fabric was FR2.
** MASK USE: The M42 mask was originally planned to be used for trials 10 and 11. Since the only difference between the M40 and M42 is the hose attachment (which would not have been used in this study), only the M40 masks were used. The MCU2P mask was uncomfortable for 6 of the 12 subjects. Those 6 wore the M40.

- O = Candidate design JSLIST-Overgarment. 1-5 are the 5 candidate fabrics: 1 and 2 are Fire Retardant (FR) fabrics, 3,4,5 are Non-FR (NFR) fabrics. 6,7,8,9,11,14 are the currently used garments, controls in these tests: SAR = Saratoga (Marine), BDO = Battledress Overgarment (Army, Air Force), CPO = Chemical Protective Overgarment (Navy), and CPU = Chemical Protective Undergarment (Army). 10 is Vapor Protective FR Undergarment (VPFRU). TBDU = Temperate Battledress Uniform (Army). CVC = Combat Vehicle Crewman Coverall (Army). Masks were worn with second skin (chemical protective interface between mask and hood).
- All trials were comprised of moderate exercise (~400 W) and were conducted in MOPP 4 (mask filters in place), with no other mission equipment (i.e. helmets, flak vests, load bearing equipment, etc.).
- Trials 1 thru 8; 9 and 5; 9 and 12; 10 and 11; 12 and 13; 13 and 14; were compared in separate analyses.

Table 2. GARMENT TRIALS - FIELD STUDY

Yuma Proving Ground, Arizona

12 subjects attempted trials 1-9; 9 different subjects attempted trials 10-13

GARMENT TRIALS		DUTY UNIFORM	MASK
1.	OFR 1	TBDU	M40
2.	OFR 2	TBDU	M40
3.	ONFR 1	TBDU	M40
4.	ONFR 2	TBDU	M40
5.	ONFR 3	TBDU	M40
6.	SAR-CONTROL	TBDU	M40
7.	BDO-CONTROL	TBDU	M40
8.	DNFR 1	NONE	MCU2P
9.	SAR-CONTROL	NONE	MCU2P
10.	VPFRU	CVC	M42
11.	CPU-CONTROL	CVC	M42
12.	AFR 2	AVC	M43
13.	BDO-CONTROL	AVC	M43

- O = Candidate design JSLIST-Overgarment. Trials 1-5 are the 5 candidate fabrics designed as overgarments: Trials 1 and 2 are Fire Retardant (FR) fabrics, Trials 3-5 are Non-Fire Retardant (NFR) fabrics. Trial 8 is candidate NFR 1 fabric designed as Duty Uniform. Trials 6, 7, 9, 11, and 13 are the currently used garments, controls in these tests: SAR = (Marine) Saratoga, BDO = (Army, Air Force) Battledress Overgarment, and CPU = (Army) Chemical Protective Undergarment. Trial 10 is candidate Vapor Protective FR Undergarment (VPFRU). Trial 12 is candidate Aviator Design Overgarment in FR 2 fabric. TBDU = (Army) Temperate Battledress Uniform. CVC = (Army) Combat Vehicle Crewman Coverall. AVC = (Army) Aviator Coverall

- Half the subjects wore the standard Green or Black Vinyl Overboots, half wore the prototype MULOs. Half wore the standard vinyl gloves and half wore the prototype gloves. The standard and prototype boots and gloves were not compared in out study. During MOPP 2 walks, helmets and boots were worn, gloves and hoods carried, along with two (full) 1-liter canteens. During MOPP 4 walks, helmets, boots, gloves and hoods were worn, and (full) canteens were carried.

INFORMATION PERTAINING TO BOTH CHAMBER AND FIELD STUDIES

After briefings on the purpose, procedures, and potential risks of the study, volunteers signed a statement of informed consent. Prior to any testing, all volunteers were medically screened and cleared by a physician, and were selected as test subjects only after they had been judged fit to participate in this study. No pregnant women and no one with a history of heat injury or chronic respiratory illness, heart disease, or orthopedic problems was selected. Investigators adhered to guidelines established for research on humans in USARIEM Memo 70-25, AR 70-25 and USAMRDC 70-25 on the Use of Volunteers in Research.

Throughout this report, the terms "Garment Trials", "Garments", and "Trials" (with the appropriate number), will refer to the garments tested and/or their test trials in the environmental chamber and in the field, as listed in Tables 1 and 2. (e.g. "Subjects in garment 7 were able to test longer; trial 7 was longest; there were 9 garment trials for volunteers in group 1".) When possible, the garment tested in both the chamber and the field have the same trial number designation. In both studies the test designs were counterbalanced and each volunteer served as his/her own control (i.e. each test subject participated in each comparison trial; each wore the prototype JSLIST garments and the current standards as the control garments). Data from male and female subjects were combined in the statistical analyses.[1]

Garment Comparisons

In both the chamber and field studies, the five prototype fabrics constructed as overgarments (Garment Trials 1-5) were compared to the BDO (Trial 7) and the SAR (Trial 6) controls (all worn over the TBDU). In the chamber study, the CPO worn over the TBDU (Trial 8) was also used as a control. In the chamber, the fabric NFR3 constructed as an overgarment (Trial 9) was compared to the duty uniform design (Trial 12) to determine if the sizing/fit affected heat stress. Also in the chamber, Trials 5 (ONFR 3 with TBDU) and 9 (ONFR3 with no duty uniform) were compared to measure the affect of the duty uniform worn with the overgarment. In the field, Trials 8 and 9 compared the prototype vs control

[1] Within the time frame and scope of these studies it was not possible to control for menstrual cycle phase in female subjects (i.e. conduct all trials within either the follicular or luteal phase, for each subject). Carefully counterbalanced trials helped minimize possible affects of variability in baseline temperatures due to cycle phase.

garments each worn without the TBDU. In both studies, Trials 10 vs 11 compared the prototype vs control chemical protective undergarments. In the chamber, Garment Trials 12 vs 13 tested the effect of ambient temperature (35°C and 24°C, respectively), while Garment Trials 13 vs 14 tested the prototype vs the control at 24°C. In the field, Garment Trials 12 vs 13 compared the prototype aviator's design garment to the control.

Physiological Measurements

During all heat exposures and all garment testing, heart rate (HR) and rectal temperature (T_{re}) were monitored. During all garment testing, skin temperature (T_{sk}) was measured by thermistors (YSI) taped to the skin at 4 sites (chest, calf, thigh, forearm). Body and clothing weights were measured pre and post tests, to estimate sweating rates. During both studies, preliminary measurements included height, weight and estimation of percent body fat via 4 skinfold measurements (Durnin & Womersley, 1974).

Subjective Measurements

Three questionnaires were administered to the test participants during the course of both the field and chamber studies: (1) the Profile of Mood States (POMS), (2) the Dishman Self-Motivation Inventory, and (3) the Subjective Heat Illness questionnaire (SHI). The three questionnaires are reproduced in Appendix A. Profile of Mood States (POMS). The POMS, a 65-item questionnaire (McNair, Lorr, & Droppelman, 1981), assesses six mood states: tension, depression, anger, vigor, fatigue, and confusion. The POMS has demonstrated the ability to discriminate among college students, soldiers, and elite athletes (Johnson & Merullo, 1997; Morgan & Pollack, 1977), and was used to determine a pre-test mood profile for the JSLIST volunteers. Dishman Self-Motivation Inventory. The Dishman, a 40-item questionnaire designed to measure motivation to adhere to exercise training programs (Dishman & Ickes, 1981), has been shown to be a reliable and valid measure of "persistence motivation" (Dishman, Ickes, & Morgan, 1980). The Dishman has demonstrated the ability to discriminate among college students and military personnel and was used in this study to determine pre-test motivation in the JSLIST volunteers. Subjective Heat Illness Questionnaire (SHI). The SHI (Johnson & Merullo, 1993), a 22-item subscale of the USARIEM Environmental Symptoms Questionnaire (Sampson, Kobrick, & Johnson, 1994), assesses subjective reports of heat-related symptomatology and has been shown to vary systematically as a function of days into heat acclimatization,

as a function of dietary salt intake during heat acclimatization, and as a function of pack-load configuration during road marches (Johnson, Knapik, & Merullo, 1995; Johnson & Merullo, 1993). The SHI was used in this study to make a comparative evaluation of the various chemical protective clothing ensembles during heat exposure.

Minimizing Risks to the Subjects

The procedures in this study were within the framework, restrictions and safety limitations of the USARIEM Type Protocol for Human Research Studies in the areas of Thermal, Hypoxic and Operational Stress, Exercise, Nutrition and Military Performance.[2] Volunteers were medically cleared before participation, to exclude those with previous heat injury, pregnant women, and others for whom the combined stress of exercise and hyperthermia may have posed a greater hazard than for normally healthy persons. For the Field Study, a physician as well as a trained medic and ambulance service were on site at all times. (There was a shaded rest area at the test site, and the post clinic was about a 15 min ride from the test site.) For the Chamber Study, a physician was on call or on site at all times (as specified by the USARIEM Type Protocol). During the field study, drinking water (as well as a commercially available sport drink) was available at all times during testing, and subjects were encouraged to drink at least 500 ml per 30 min to remain hydrated. During the chamber study, a water drinking regimen was in place during testing. During the Field Study, heart rate and rectal temperature were monitored and recorded at 5-min intervals during all thermal strain evaluations, and subjects were closely supervised at all times. During the Chamber Study, heart rate and rectal temperature were continuously monitored and recorded. Testing was discontinued for any subject who exhibited symptoms or signs of impending heat injury, whose heart rate reached or exceeded 90% of age estimated maximal (220-age in years) for 5 consecutive minutes, if heart rate reached 95% of age estimated at any time, if T_{re} reached 39.5°C, or climbed at a rate greater than 0.6°C in five min during exercise (or reached 39.2°C during rest), if the subject requested withdrawal, or at the discretion of the investigator or the medical monitor, whichever came first.

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[2] Approved 7 March 1996 (December 1994 Type Protocol for Field Study). The type protocol provides information and explanations about conditions, standards and safeguards, in order to serve as an encompassing framework for specific in-house studies in its general subject area. It is to be used as a reference to facilitate the understanding and review of specific study protocols which conform to its provisions, and thus do not exceed the degree of risk, and safety limits herein stipulated (reference para 18, USAMRDC Reg 70-25, 3 May 1989).

Other Controls and Precautions

We requested (of supervisors and of the volunteers themselves) that test subjects be exempted from strenuous duty 24 h prior to and after tests, that they receive recovery time at least equal to the test time, immediately following each test, and that they not be responsible for additional duties (i.e. charge-of-quarters) which may have interfered with normal eating and sleeping, during testing. Test subjects were asked to get a minimum of six hours of sleep each night, and stay well hydrated throughout the study (eat regular meals and drink plenty of non-alcoholic, non-caffeinated fluids). For the 24 hours prior to testing, subjects were asked to refrain from drinking alcohol or from taking any over-the-counter medications, and from participating in any heavy/vigorous exercise and any exercise that was not part of their normal routine. On test days, smokers were asked to refrain from smoking for at least 2 hours before testing, until the experiments were done for the day. Test subjects were asked to eat a light breakfast or lunch before testing (and were provided examples of light meals). Subjects were requested to adhere to these restrictions because some medications such as aspirin and cold remedies, and smoking and drinking alcohol, and foods and fluids consumed, can all affect body temperature regulation.

CHAMBER STUDY

METHODS

Subjects

Twelve healthy volunteers (10 male, 2 female), from the Test Volunteer Platoon at U.S. Army Natick Research, Development, and Engineering Center (USANRDEC), Natick MA, and from the USMC base at Twentynine Palms CA, participated as test subjects. We did not expect to see differences in heat strain based on gender, and have not compared responses between the male and female volunteers. The subjects' characteristics are as follows, mean (SD), n=12: age 23 (4) yrs, height 176 (9) cm, weight 75.61 (12.78) kg, body fat 18.9 (6.9) %, body surface area 1.92 (0.18) m^2. POMS psychological mood scores were typical of military populations: the predominant mood was vigor with lower scores on tension, depression, anger, fatigue, and confusion. This "iceberg" profile of moods (see Figure 1) is characteristic of military populations (U.S. Army soldiers, Special Operations Forces, and U.S. Marines) (Johnson & Merullo, 1996), and of elite middle and long distance runners (Morgan & Pollack, 1977). Dishman persistence motivation scores (mean = 166, s.d. = 21) were higher than the college norms (mean = 140, s.d. = 19), which is typical of U.S. military samples such as Army War College students (mean = 158, s.d. = 17) and Special Operations Forces (mean = 167, s.d. = 17).

Experimental Design and Procedures

This study was a counterbalanced, repeated measures test for 12 subjects serving as their own controls. Because there were 14 different garment trials that were not all to be compared to one another, the trials were divided for testing in three segments. Statistical comparisons were among Garment Trials 1-8, and between Garment Trials 5 and 9, 10-11, 9-12, 12-13, and 13-14. The test matrix is displayed in Table 1.

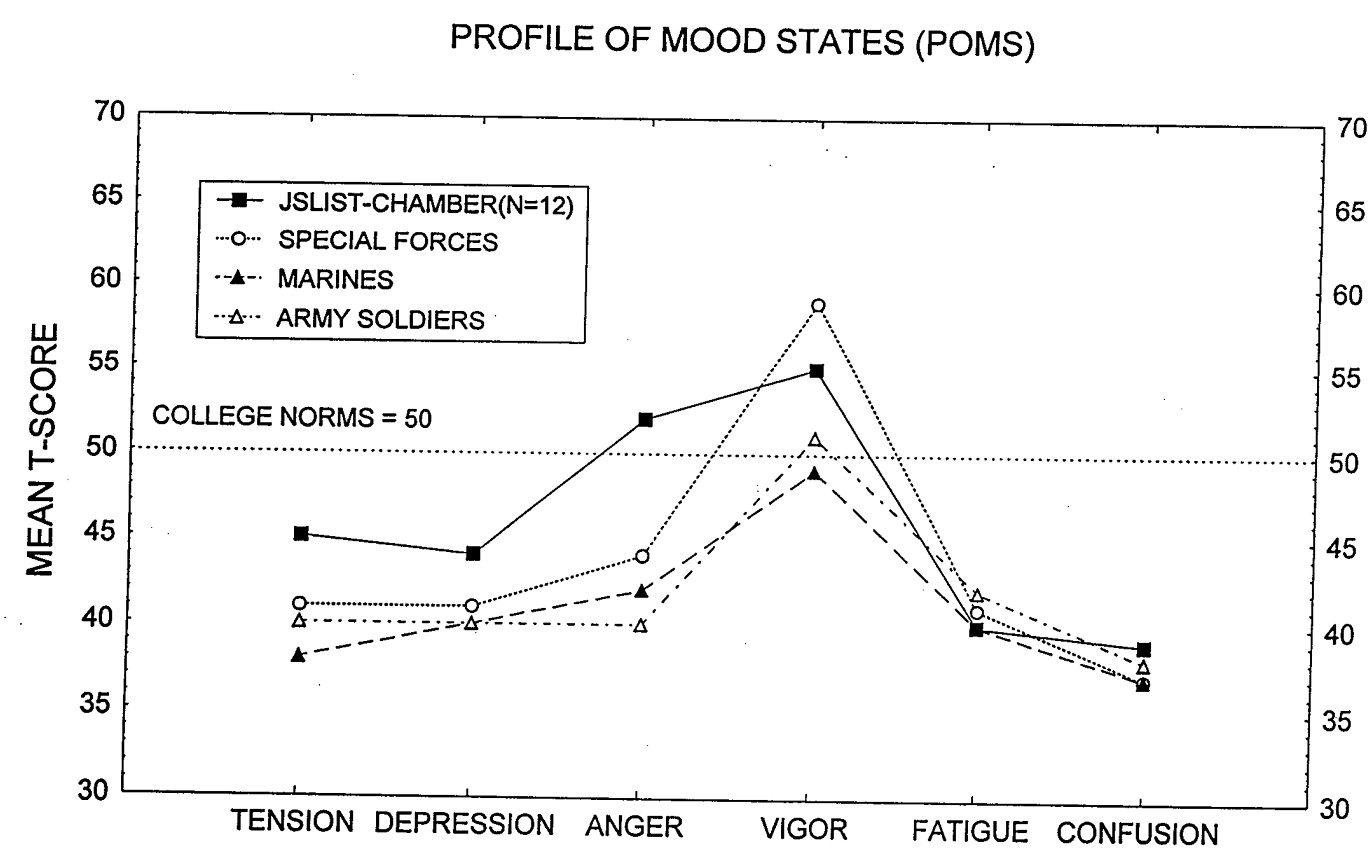
All testing was conducted during 9 consecutive weeks from early July, through August, to early September 1996. This time-span includes a 2-4 day exercise heat acclimation process, preliminary measurements and a familiarization session, and garment trials. Acclimation, preliminary measurements and familiarization were conducted at USARIEM;

the garment trials were conducted in an environmental chamber at the Navy Clothing and Textile Research Facility (NCTRF).

Preliminary measurements. Preliminary measurements included height, weight and estimation of percent body fat via 4 skinfold measurements (Durnin and Womersley, 1974) and garment, mask and boot sizing. During the preliminary measurements phase, the POMS and Dishman subjective questionnaires were administered, and the SHI was administered for familiarization. Also prior to the garment tests, subjects participated in a familiarization session. Familiarization consisted of subjects dressing in each of two control garments (the BDO and the SAR), and walking on a treadmill (for 15 min at a time) at one to three treadmill speeds/grades so that we could determine the appropriate speed/grade to elicit ~400 W metabolic rate (moderate exercise). Metabolic rates were determined by open circuit spirometry (SensorMedics Horizon Metabolic Cart). The garment familiarization session was conducted in a "room" temperature (18-24 °C [65-75 °F]) environment. Table 3 shows the mean metabolic rates determined for the two selected treadmill speeds. To most closely approximate 400W exercise intensity, two walking speeds were selected. Eight subjects performed all of their garment tests while walking at 2.8 mph (1.25 $m \cdot s^{-1}$); four subjects walked at 3.0 mph (1.34 $m \cdot s^{-1}$). Of the 8 who tested at 2.8 mph, one did not familiarize in the BDO; of the 4 who tested at 3.0 mph, one did not familiarize in the SAR.

Insert Figure 1 here

Figure 1



PROFILE OF MOOD STATES (POMS)
MEAN T-SCORE
70
65
60
55
50
45
40
35
30
JSLIST-CHAMBER(N=12)
SPECIAL FORCES
MARINES
ARMY SOLDIERS
COLLEGE NORMS = 50
TENSION
DEPRESSION
ANGER
VIGOR
FATIGUE
CONFUSION

Table 3. Metabolic Rates (Watt) for the two walking speeds used during testing

Treadmill Speeds (0% grade) Mean (SD)			
BDO		SAR	
2.8 mph ($1.25\ m \cdot s^{-1}$)	3.0 mph ($1.34\ m \cdot s^{-1}$)	2.8 mph ($1.25\ m \cdot s^{-1}$)	3.0 mph ($1.34\ m \cdot s^{-1}$)
	373 (39) W n=4	414 (57) W n=8	
433 (67) W n=7	389 (29) W n=3	419 (59) W n=7	385 (14) W n=3

When a subject did not do the familiarization in both the BDO and SAR, means with and without that subject are included. (One of the 12 subjects did not familiarize in the BDO, and one did not familiarize in the SAR.)

Acclimation. Prior to any garment tests, subjects participated in a 2-4 day exercise-heat acclimation process. Acclimation prior to testing minimizes changes in thermoregulatory status during testing, and provides an advantage to subjects so that they have a better chance of completing the garment tests. This exercise-heat acclimation program was intended to partially heat-acclimate the subjects. The reason for this is two-fold: 1) The most dramatic and large acclimation changes in rectal temperature (T_{re}) and heart rate (HR) occur in the first 3-5 days of exercise-heat exposure (Wenger, 1988); 2) All of the volunteers had been exposed to hot environmental conditions, so were already partially acclimatized. Since all testing took place in the summer, the soldiers living in Massachusetts had already been at least partially acclimatized (ambient temperatures in the 80s and 90s°F, or ~30-35°C), and were therefore acclimated in the environmental chamber for four days. The Marine volunteers had been living in Southern California where ambient temperatures had been very hot (~90s and 100s °F or ~35-40°C), and were also at least partially acclimatized. The Marines acclimated in the chamber for 2 days prior to testing. (No added acclimation days were dispersed among the test days because of the lengthy testing schedule.)

Each day of heat acclimation consisted of 110 min in the climatic chamber. It included 10 minutes of standing baseline measurements, followed by 100 min of treadmill walking ($1.56\ m \cdot s^{-1}$ [3.5 mph] at 4% grade). The environmental conditions during acclimation were:

dry bulb temperature (T_{db}) 40 °C (±1°C) (104°F), dew point temperature (T_{dp}) 19.2 °C (±1°C) (66.6°F), ~30% relative humidity (rh), with minimal wind speed (~1.1 m·sec^{-1} [2.5 mph]). Heart rate (HR) and rectal temperature (T_{re}) were monitored continuously during the 110-min heat exposure. The subjects wore shorts, tee shirt, socks and comfortable running shoes. Due to the necessity of small chamber testing, during the first 2 days only of acclimation for the soldiers, cycle ergometer exercise at a similar work rate (based on HR) replaced some of the treadmill walking. Minimally clothed (shorts and T_{re} instrumentation only) weights were measured pre- and post-test. Subjects consumed 500 ml of water in the ~45 min prior to entering the heated chamber, and then consumed 300 or 350 ml every 20 min during heat exposure. Based on their pre- and post-acclimation session weight changes, and on their fluid consumption preferences, the volume of water needed (to maintain hydration levels within 2% of baseline weights and satisfy thirst) was determined for each subject. This rate of rehydration (500 ml pre test followed by 300 ml every 20 min) was based on a formula by Shapiro, Pandolf & Goldman (1982), and has been shown to estimate sweat loss within 1% for male volunteers testing in similar environmental, exercise and clothing conditions as those of this study (Montain, et al, 1994). During exercise-heat acclimation, subjects were progressively familiarized with wearing the chemical protective mask, while they walked on the treadmills. Our experience was that mask use (especially with the filters in as they were during this study) often limited endurance time in subjects unaccustomed to wearing masks. Mask familiarization was designed to help subjects tolerate the mask during the garment trials. Mask familiarization consisted of subjects wearing the mask for progressively longer periods during each acclimation session: approximately 15-20 min on day 1, ~20-35 min day 2, ~35-50 min day 3, and so on, until the masks were worn for 60 min by the end of the acclimation process. By the end of their 2- or 4-day acclimation programs, all of the volunteers tolerated their masks for 60 minutes.

Experimental Garment Trials. Experimental trials each test day were identical except for the test garment worn, and for trials 13-14, the chamber temperature. Environmental conditions for Garment Trials 1-12 were: T_{db} 35 °C ± 1°C (95°F), T_{dp} 23 °C ± 1°C, 50 %rh, and for Garment Trials 13-14 were: T_{db} 24 °C ± 1°C (75 °F), T_{dp} 12.9 °C ± 1°C, 50 %rh. Wind speed was ~1.1 m·sec^{-1} (2.5 mph). Subjects dressed in MOPP level 4 for all garment trials. (MOPP 4: CB protective garment on, protective mask on, hood, overboots [no overboots for trials 10 and 11], gloves on, all garment openings are closed.) In order that fluids could be easily monitored, and to maximize mask hygiene, tygon tube drinking

"straws" were used for drinking from plastic water bottles (one end of tygon tube inserted into the drinking water, the other end of the tube inserted under the mask) instead of the integral mask-to-canteen drinking system. The subjects consumed 500 ml water during the ~60 min prior to entering the chamber, and were given 300 or 350 ml of water every 20 min during testing (as determined for each subject). Minimally clothed and fully dressed weights were measured pre- and post-test. Physiological measurements included T_{re}, HR, $\bar{T}_{sk}$, and sweating rate. The subjective questionnaire was administered pre-chamber, during the first 10 min of heat exposure, and post-exercise (see Appendix). Each trial was (scheduled to be) 110 min in the chamber, consisting of 10 min of standing baseline measurements, followed by 100 min of moderate intensity exercise (~400W). (Many subjects were unable to complete the 110 min tests - see results.) The exercise consisted of treadmill walking at either 2.8 or 3.0 mph (1.25 or 1.34 $m \cdot sec^{-1}$), 0% grade, as determined during familiarization. All garment trials for each individual subject were done at the same treadmill settings. Volunteers tested 2-3 days per week, one heat exposure per day, with at least one day off between test days.

Physiological Measurements. During all testing HR was obtained from chest electrodes connected by wires to a battery operated transmitter worn by the volunteer. The electrocardiogram was continuously telemetered to a (Hewlett Packard) recorder/oscilloscope. HR was manually recorded from the recorder/oscilloscope every 5 min. As a back-up, portable heart rate "watches" with chest electrode bands (Polar Vantage) were also used. Rectal temperature was measured by use of a flexible thermistor thermometer (YSI) inserted approximately 10 cm beyond the anal sphincter, and continuously monitored via an on-line data acquisition system (Hewlett Packard). Skin temperature (T_{sk}) was measured by thermistors (YSI) taped to the skin at 4 sites (chest, forearm, calf, thigh), and continuously monitored via the data acquisition system. Mean weighted skin temperature ($\bar{T}_{sk}$) was calculated (Ramanathan, 1964). Whole body sweating rate and evaporative sweating were estimated from changes in minimally clothed and fully dressed weights taken before and after each test. Corrections were made for water ingested, voided and trapped (unevaporated) in the garments. Evaporative heat loss from the clothing surface was calculated as: Evaporative Heat Loss ($W \cdot m^{-2}$) = (evaporated sweat, $g \cdot min^{-1}$) x ($0.68\ W \cdot h^{-1} \cdot g^{-1}$) x (60 min) ÷ m^2.

Subjective Measurements. The SHI was administered three times each test day: (1) pre-chamber, for rating symptoms felt during suiting up and preparing to enter the heat

chamber; (2) during the first 10 minutes of chamber exposure, for rating symptoms felt during chamber exposure prior to walking; and (3) post-chamber, for rating symptoms felt during the 100 minutes of treadmill walking in the heat chamber (due to voluntary and medical withdrawals, actual treadmill walking time was often less than 100 minutes). The SHI was scored in accordance with standard procedures (Johnson & Merullo, 1993), and comparative analyses were made of the trial garments according to the overall design of the study.

Statistical Analyses. Sample size estimation (α=0.05, β=0.20, based on data from the BDO and Saratoga garments) determined that a minimum of 11 test subjects were needed for our garment comparisons (Borenstein & Cohen, 1988). Data from male (n=10) and female (n=2) subjects were combined in the analyses. Multifactor analysis of variance (anova, subject x garment x time) was used to analyze data for the variables (T_{re}, ΔT_{re}, $\bar{T}_{sk}$, HR) measured over time (per 5-min), (subject x garment for those variables not measured repeatedly over time such as endurance time and sweating rate). Paired T-Tests were used to compare non-repeated measures variables between two garments, (i.e. Test Time and Sweating Rate variables for garment comparisons of trials 5 and 9, 9 and 12, 12 and 13, 13 and 14). For measured variables, garment trials 1-8 were compared, and trials 9 vs 5, trials 10 vs 11, 13 vs 14, 12 vs 13, and 9 vs 12 were compared. Where significant main effects or interactions were found, Tukey's Test of Critical Difference was used to locate significant differences ($p<0.05$). Comparison of the time course changes (ΔT_{re}; anova on difference between each 5-min variable and the value at 10-min) for T_{re} between the prototype and standard garments was also performed.

RESULTS

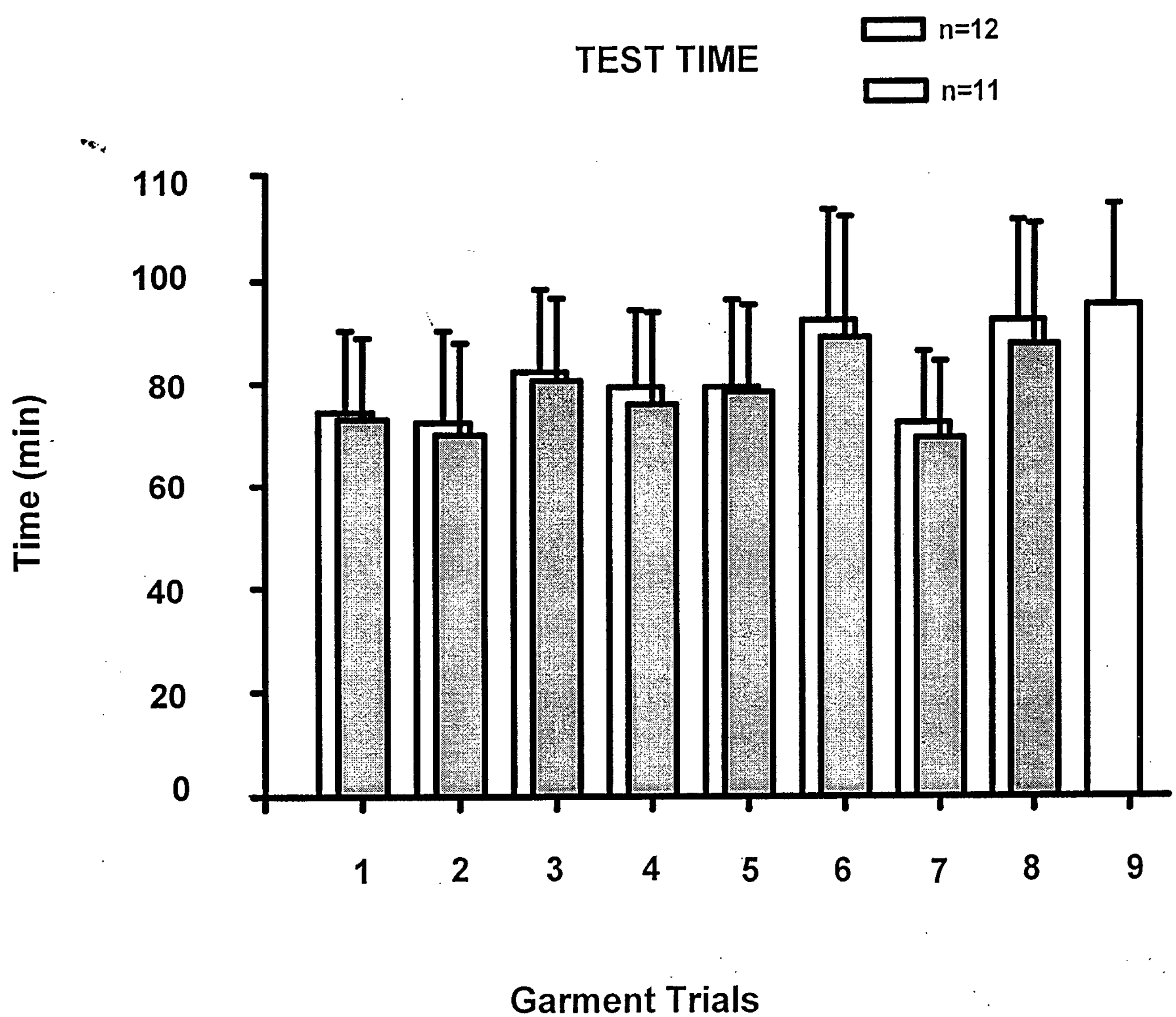
Results will be presented in sections according to the statistical comparisons; garment trials 1-8 first, then trials 5 vs 9 (subjective data: garment trials 1-9), trials 9 vs 12, trials 10 vs 11, trials 12 vs 13, and lastly garment trials 13 vs 14. Several of the Tables and Figures in this section apply to more than one comparison and for a few of the analyses reported there is no accompanying figure.

<u>Garment Trials 1-9</u>

Test Time: Tables 4 and 5 list the mean test times for each garment trial (for all garment comparisons). Figure 2 illustrates Test Time for garment trials 1-9 (Trial 9 is included to show the comparison between trials 5 [ONFR3] and 9 [ONFR3 - no duty uniform). Test time is the mean time that subjects could complete for each of the garment trials. Tests were ended because physiological safety criteria were met, if a subject felt he/she could no longer continue, or at the Investigator's or Medical Monitor's discretion. Trials 6 (SAR) and 8 (CPO), at 89 and 88 min, were significantly longer than trials 1 (OFR1), 2 (OFR2), and 7 (BDO) at 73, 70, and 70 min. (Also, trial 9 was longer than trial 5, at 95 vs 79 min.)

Insert Figure 2 here

Figure 2



TEST TIME
n=12
n=11
110
100
80
60
40
20
0
Time (min)
1
2
3
4
5
6
7
8
9
Garment Trials

Table 4. Test Times for Garment Trials 1-9

Garment Trials	1 OFR1	2 OFR2	3 ONFR1	4 ONFR2	5 ONFR3	6 SAR	7 BDO	8 CPO	9 ONFR3-
Mean (SD) n=12	73 (16)	70 (18)	81 (16)	76 (18)	78 (17)	89 (23)	70 (15)	88 (23)	---
Mean (SD) n=11					79 (17)				95 (19)
Mean (SD) n=10									94 (20)

Means for n=11 and n=10 are provided because one subject did not complete garment trial 9, and two subjects did not complete trial 12. In the trial 5 vs 9 comparison we used data only from the 11 subjects who completed both trials. In the trial 9 vs 12 comparison we used data only from the 10 subjects who completed both trials. In both tables 4 and 5, the negative sign (-) indicates that no (duty uniform) garment was worn with the test garment.

Table 5. Test Times for Garment Trials 10-14

Garment Trials	10 VPFRU	11 CPU		12 DNFR2-	13 DNFR2-	14 BDO-
Mean (SD) n=12	94 (25)	85 (26)		---	102 (15)	89 (28)
Mean (SD) n=10				88 (15)	103 (15)	

Garment Trials 10, 11 and 12 were at 35°C, 13 and 14 were at 24°C. As in Table 4, the negative sign indicates that no other (duty uniform) garment was worn with the test garment.

T_{re}: (see Figures 3a and 3b) Figure 3a illustrates the mean rectal temperatures for 12 subjects. These data were analyzed to 40 min because this was the longest time that all 12 subjects were still testing in each garment trial. In general, T_{re} for subjects in garment 5 (ONFR3) were significantly higher than in garments 2 (OFR2) and 6 (SAR). Though some significant differences exist during the early minutes of testing, more consideration should be placed on data from ~30 min on. It is in the later times that the garment trials tend to spread out with regard to physiological responses. Figure 3b illustrates T_{re} data

for 10 subjects who completed 50 min of testing in each trial. By 45 min garment 7 (BDO) emerged as the hottest along with garment 5 (ONFR3), while garments 8 (CPO) and 6 (SAR) emerged as the coolest. In all analyses, T_{re} increased over time for all garments throughout testing. (For a detailed description of each 5-min comparison, see the Statistical Comparisons in Appendix B.)

Insert Figures 3a and 3b here

Figure 3a

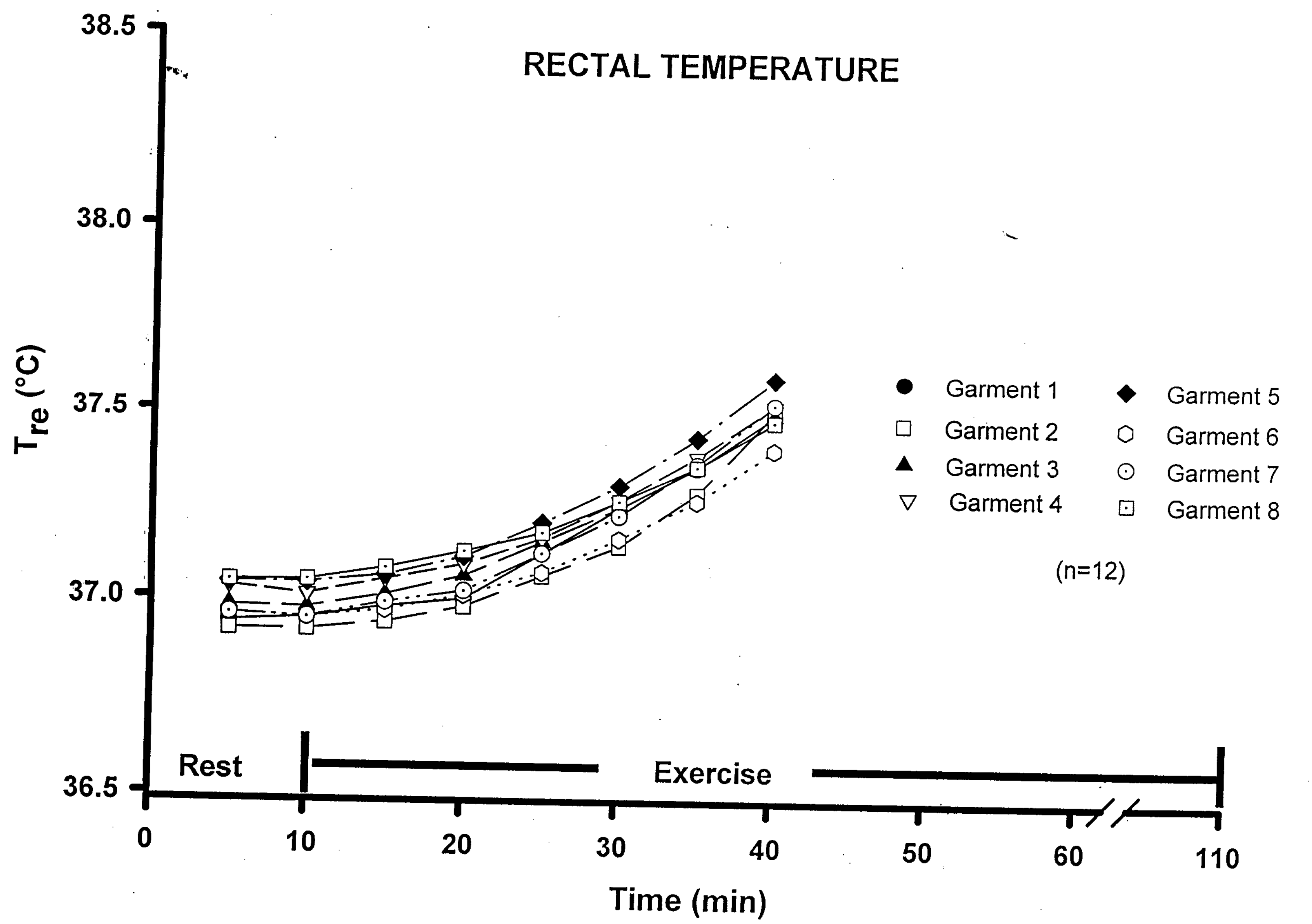
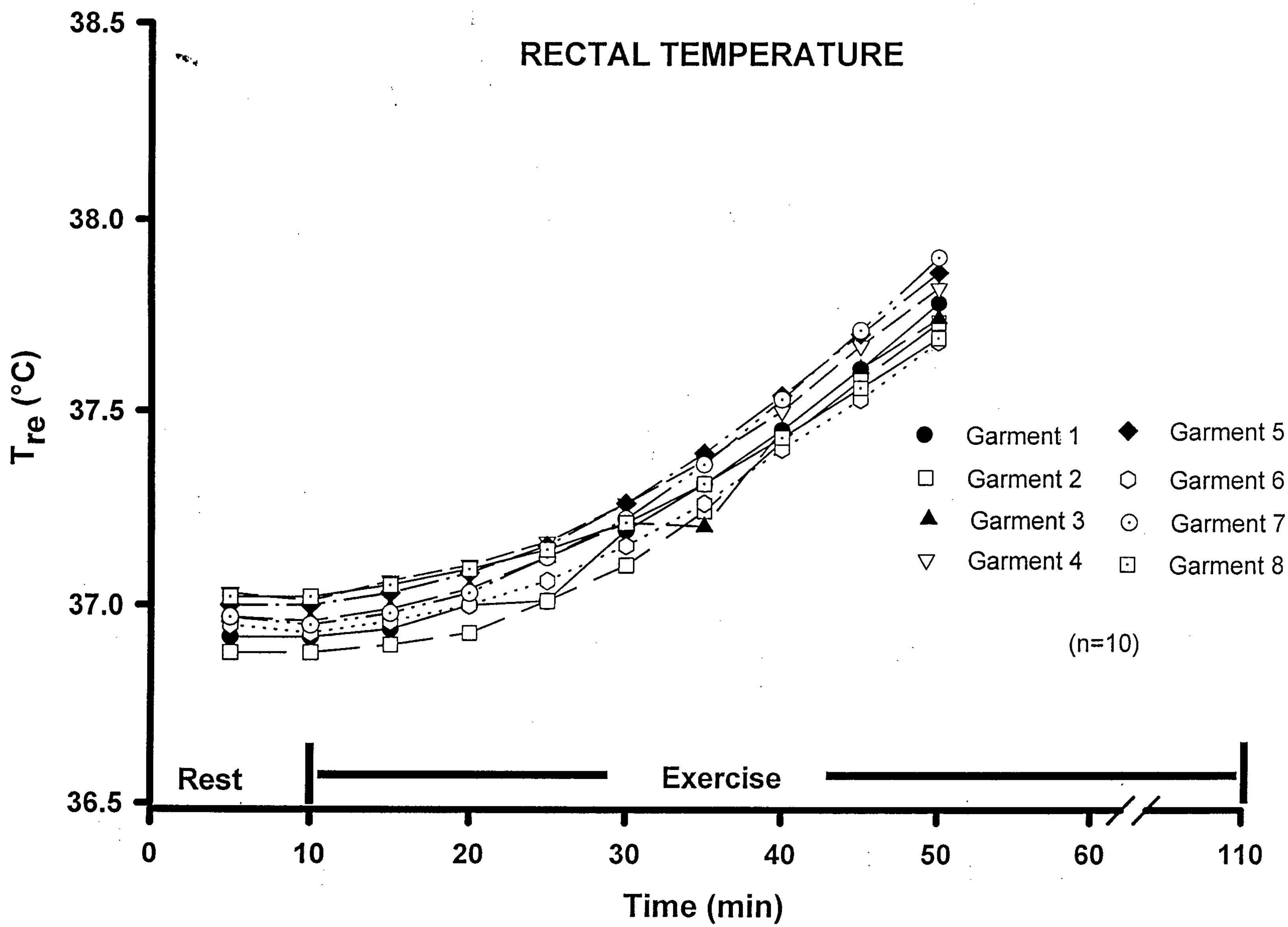

RECTAL TEMPERATURE
T_{re} (°C)
38.5
38.0
37.5
37.0
36.5
0
10
20
30
40
50
60
110
Time (min)
Rest
Exercise
Garment 1
Garment 2
Garment 3
Garment 4
Garment 5
Garment 6
Garment 7
Garment 8
(n=12)

Figure 3b


RECTAL TEMPERATURE
T_{re} (°C)
38.5
38.0
37.5
37.0
36.5
Garment 1
Garment 2
Garment 3
Garment 4
Garment 5
Garment 6
Garment 7
Garment 8
(n=10)
Rest
Exercise
0
10
20
30
40
50
60
110
Time (min)

Because the many comparisons in this analysis may have obscured differences between the JSLIST prototypes and each control, additional anovas were performed. The five JSLIST garments (Trials 1-5) were compared in separate analyses to the SAR, to the BDO, and to the CPO controls. The results of these comparisons support the results of the larger group comparisons. For the 40 min analysis with the SAR control, garment 5 (ONFR3) was consistently hotter than garments 6 (SAR) and 2 (OFR2). For the BDO and CPO comparisons, 5 was consistently hotter than 2. For the 50 min anaylsis with the SAR, garments 5 and 4 were consistently hotter than 6 and 2. For the BDO, until 35 min garments 5, 4, and 7 were hotter than 2, and by 50 min garments 7 and 5 were hotter than 3 and 2. For the CPO comparison, by 50 min garments 5 and 4 were hotter than garment 8.

Delta T_{re}: (see Figures 4a and 4b) In this report the Delta T_{re} was calculated for each 5-min value from the T_{re} at that time minus the T_{re} at 10 min. Delta T_{re} was analyzed because the variability in core temperature among subjects can mask differences. In general, these analyses show garments 7 and 5 to be the hottest, while 6 and 8 tend to be the coolest.

Insert Figures 4a and 4b here

Figure 4a

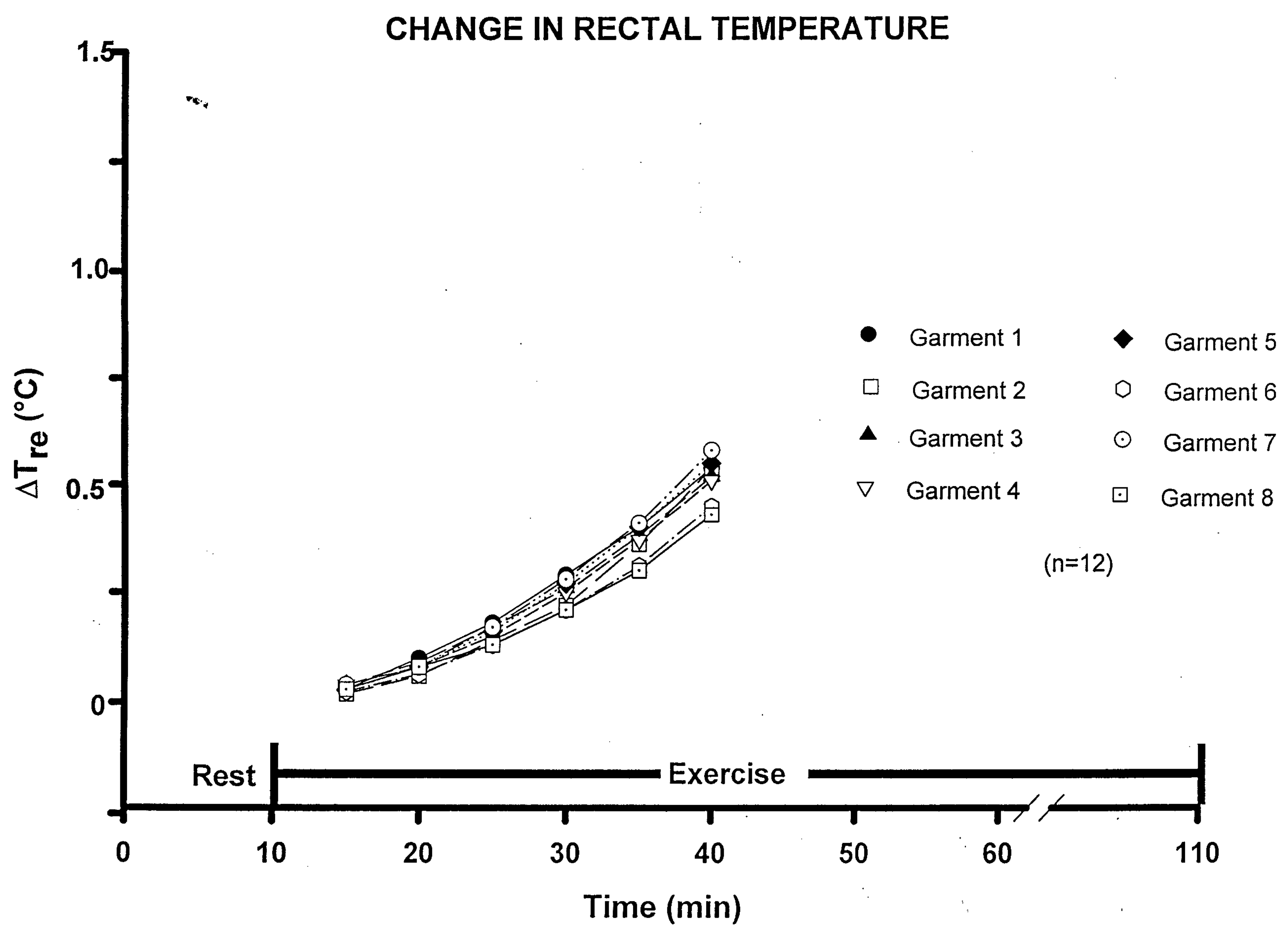
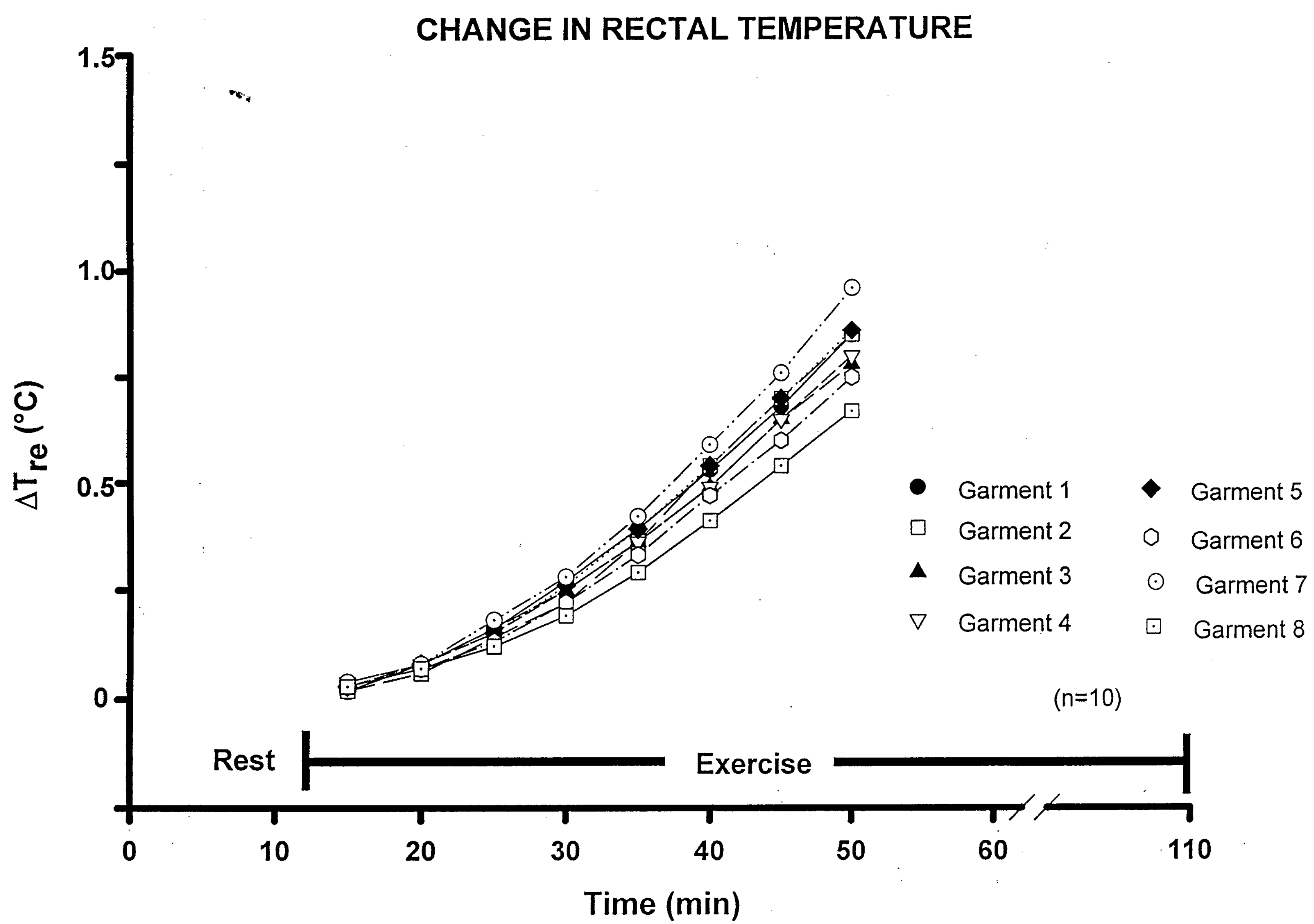

CHANGE IN RECTAL TEMPERATURE
ΔTre (°C)
1.5
1.0
0.5
0
Rest
Exercise
0
10
20
30
40
50
60
110
Time (min)
Garment 1
Garment 2
Garment 3
Garment 4
Garment 5
Garment 6
Garment 7
Garment 8
(n=12)

Figure 4b

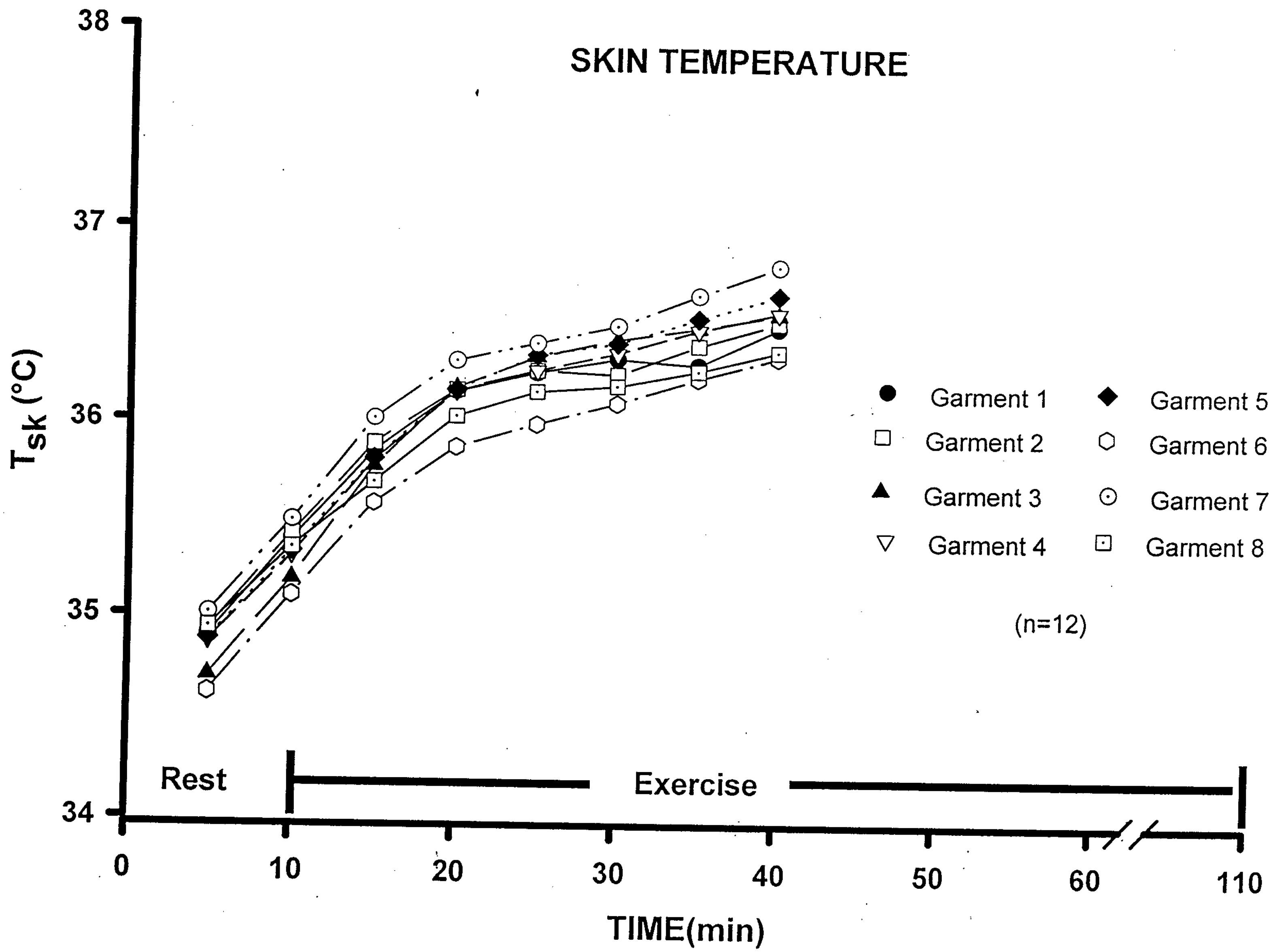


CHANGE IN RECTAL TEMPERATURE
ΔT_{re} (°C)
1.5
1.0
0.5
0
Rest
Exercise
0
10
20
30
40
50
60
110
Time (min)
Garment 1
Garment 2
Garment 3
Garment 4
Garment 5
Garment 6
Garment 7
Garment 8
(n=10)

$\bar{T}_{sk}$: (see Figures 5a and 5b) When mean weighted skin temperatures for all subjects were analyzed through 40 min, garment 7 caused significantly higher $\bar{T}_{sk}$ than 8 or 6. In this analysis, the JSLIST garments were not significantly different among themselves, nor from any of the controls. The same is seen when we analyzed the data from 10 subjects to 50 min.

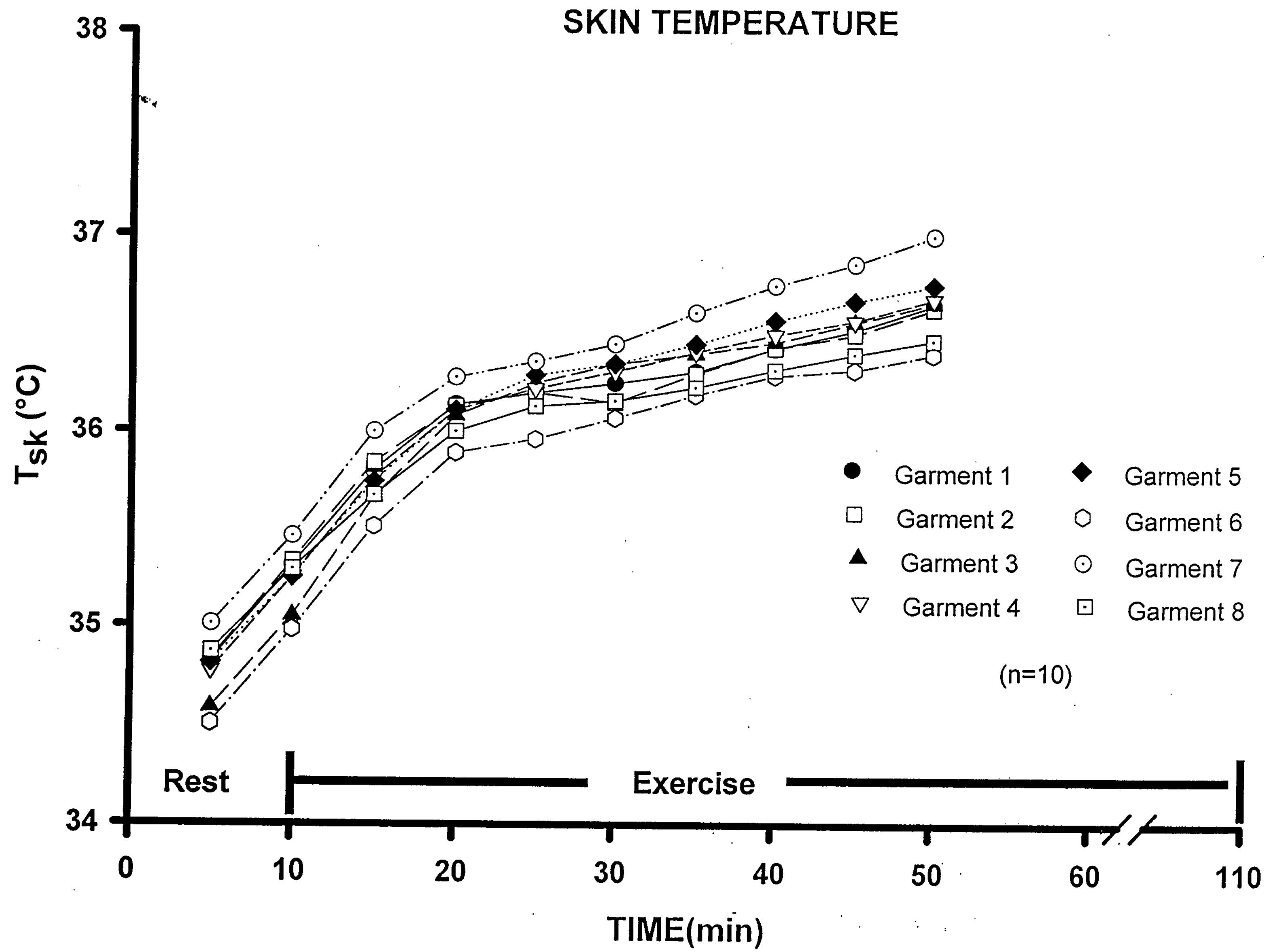
Insert Figures 5a and 5b here

Figure 5a



SKIN TEMPERATURE
T_{sk} (°C)
38
37
36
35
34
Garment 1
Garment 2
Garment 3
Garment 4
Garment 5
Garment 6
Garment 7
Garment 8
(n=12)
Rest
Exercise
0
10
20
30
40
50
60
110
TIME(min)

Figure 5b


SKIN TEMPERATURE
T_{sk} (°C)
38
37
36
35
34
0
10
20
30
40
50
60
110
TIME(min)
Rest
Exercise
Garment 1
Garment 2
Garment 3
Garment 4
Garment 5
Garment 6
Garment 7
Garment 8
(n=10)

Heart Rate: (see Figures 6a and 6b) When heart rates were analyzed, by 40 min (n=12) subjects in garment 5 had higher heart rates than those in garments 6 and 8. By 50 min (n=10) only heart rates in garments 5 and 8 were significantly different.

Insert Figures 6a and 6b here

Figure 6a

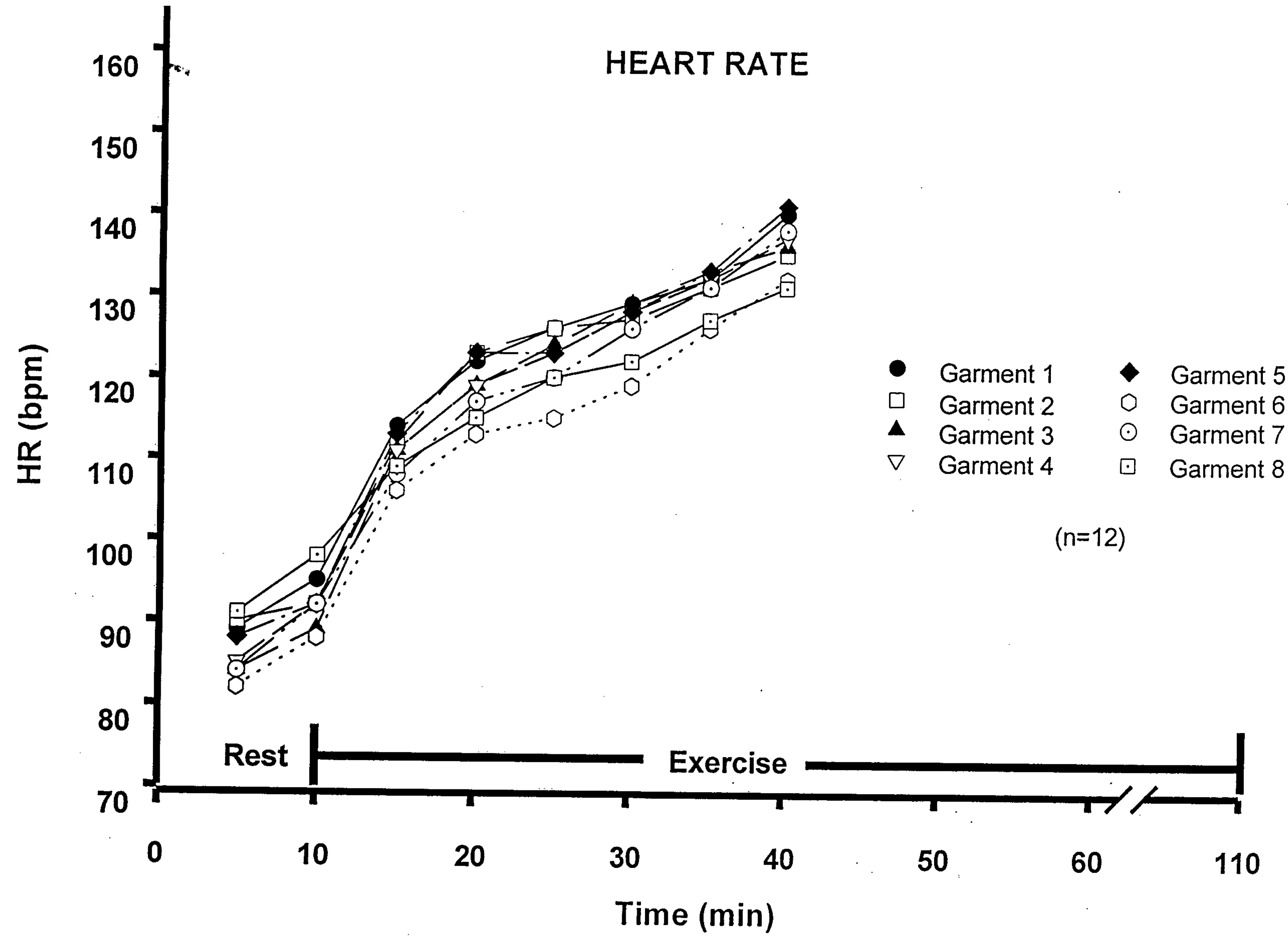
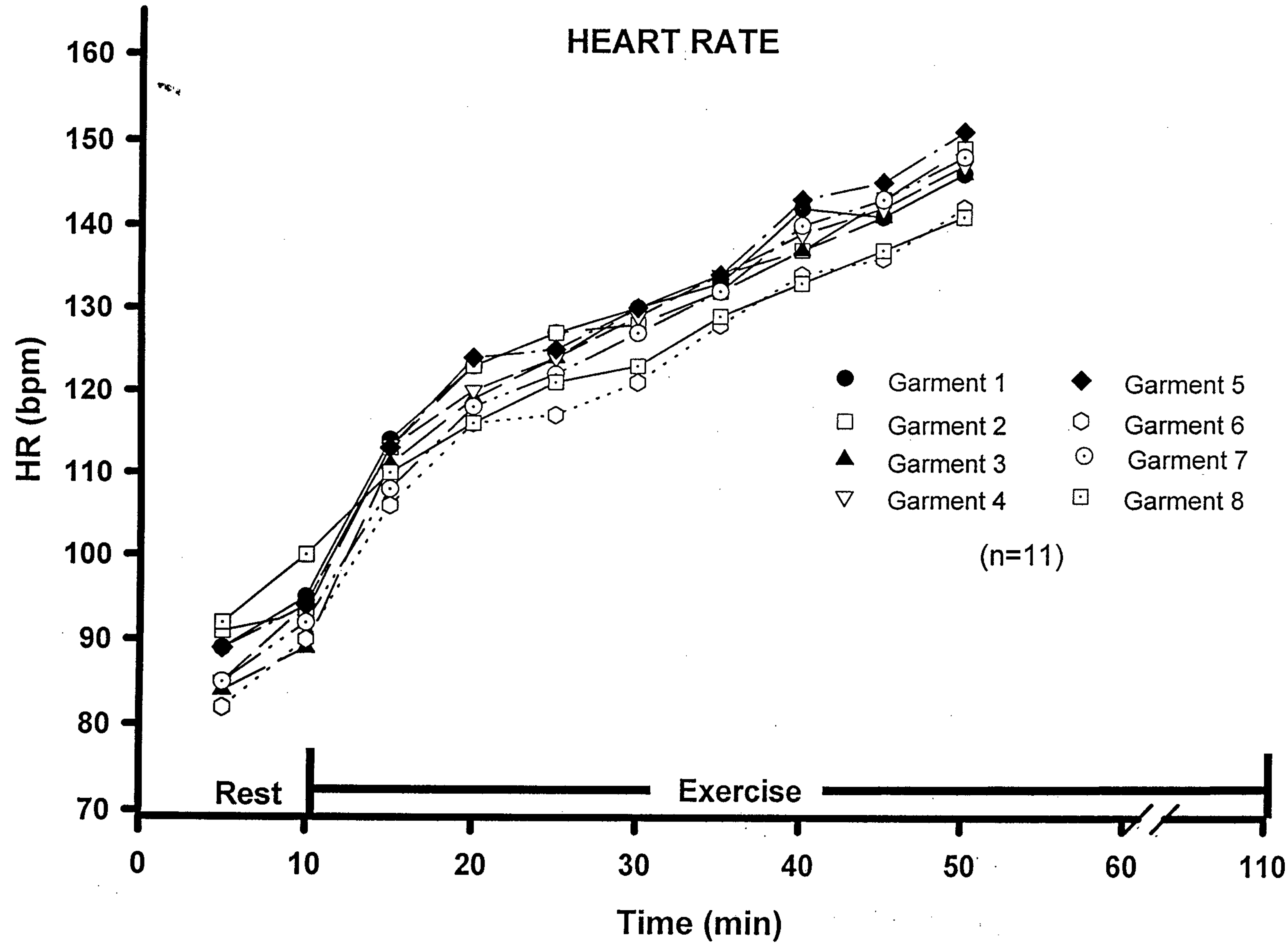

HEART RATE
HR (bpm)
160
150
140
130
120
110
100
90
80
70
0
10
20
30
40
50
60
110
Time (min)
Rest
Exercise
Garment 1
Garment 2
Garment 3
Garment 4
Garment 5
Garment 6
Garment 7
Garment 8
(n=12)

Figure 6b


HEART RATE
HR (bpm)
160
150
140
130
120
110
100
90
80
70
Garment 1
Garment 2
Garment 3
Garment 4
Garment 5
Garment 6
Garment 7
Garment 8
(n=11)
Rest
Exercise
0
10
20
30
40
50
60
110
Time (min)

Sweating Rate and Evaporative Heat Loss: (see Figures 7 and 8) Total Sweating Rate ($g \cdot min^{-1}$) was estimated from the pre- and post-weights with corrections for water ingested and voided. The test time for each subject was used to calculate the per min value. Evaporated Sweating Rate was estimated from the total, corrected for unevaporated sweat trapped in the garments. For the 1-8 garment comparison, there were no significant differences in either Total or Evaporated sweating rates. From the evaporated sweating rate and the subject's body surface area we calculated the Evaporative Heat Loss ($W \cdot m^{-2}$). These differences were not significant.

Insert Figures 7 and 8 here

Figure 7

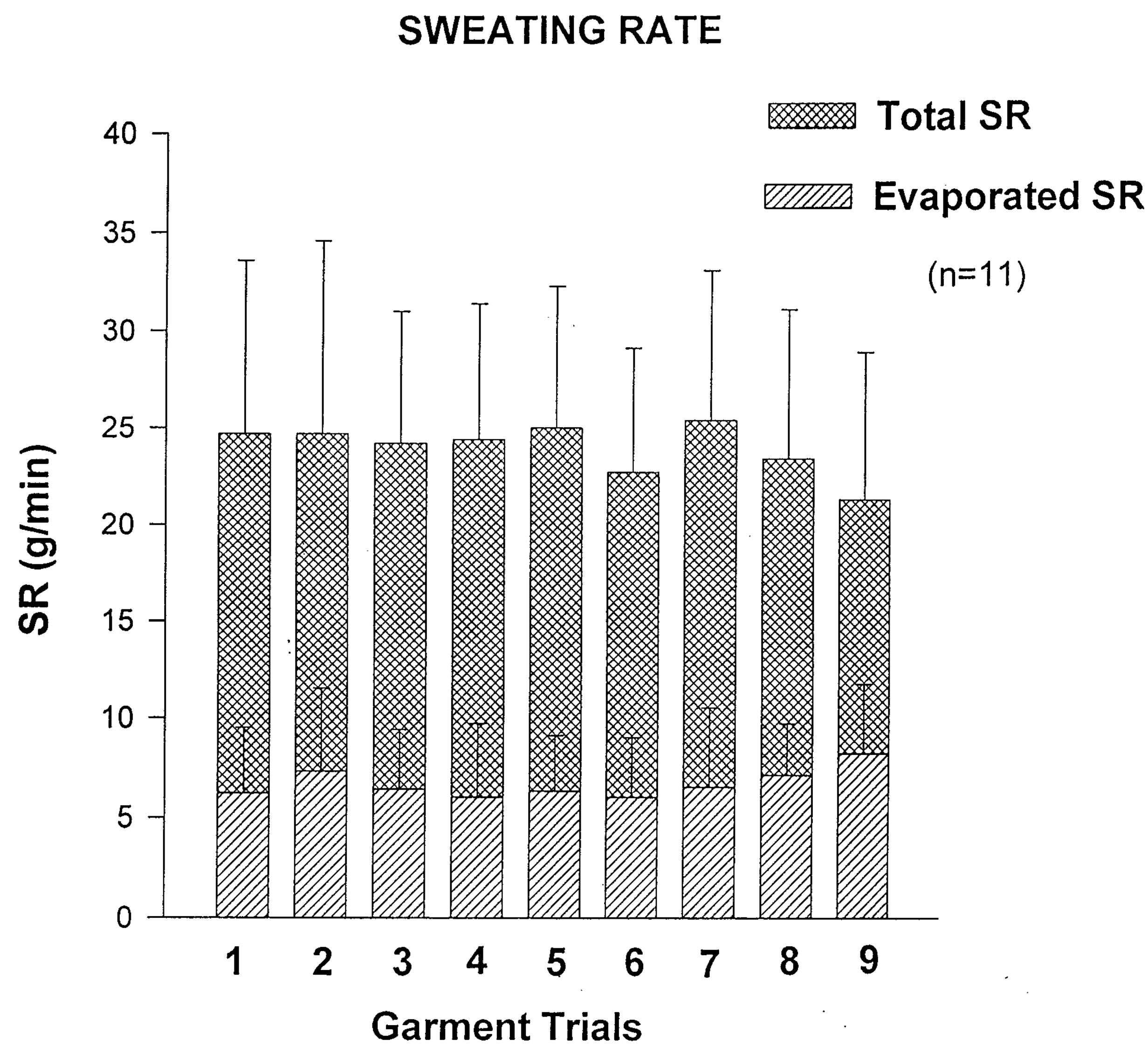
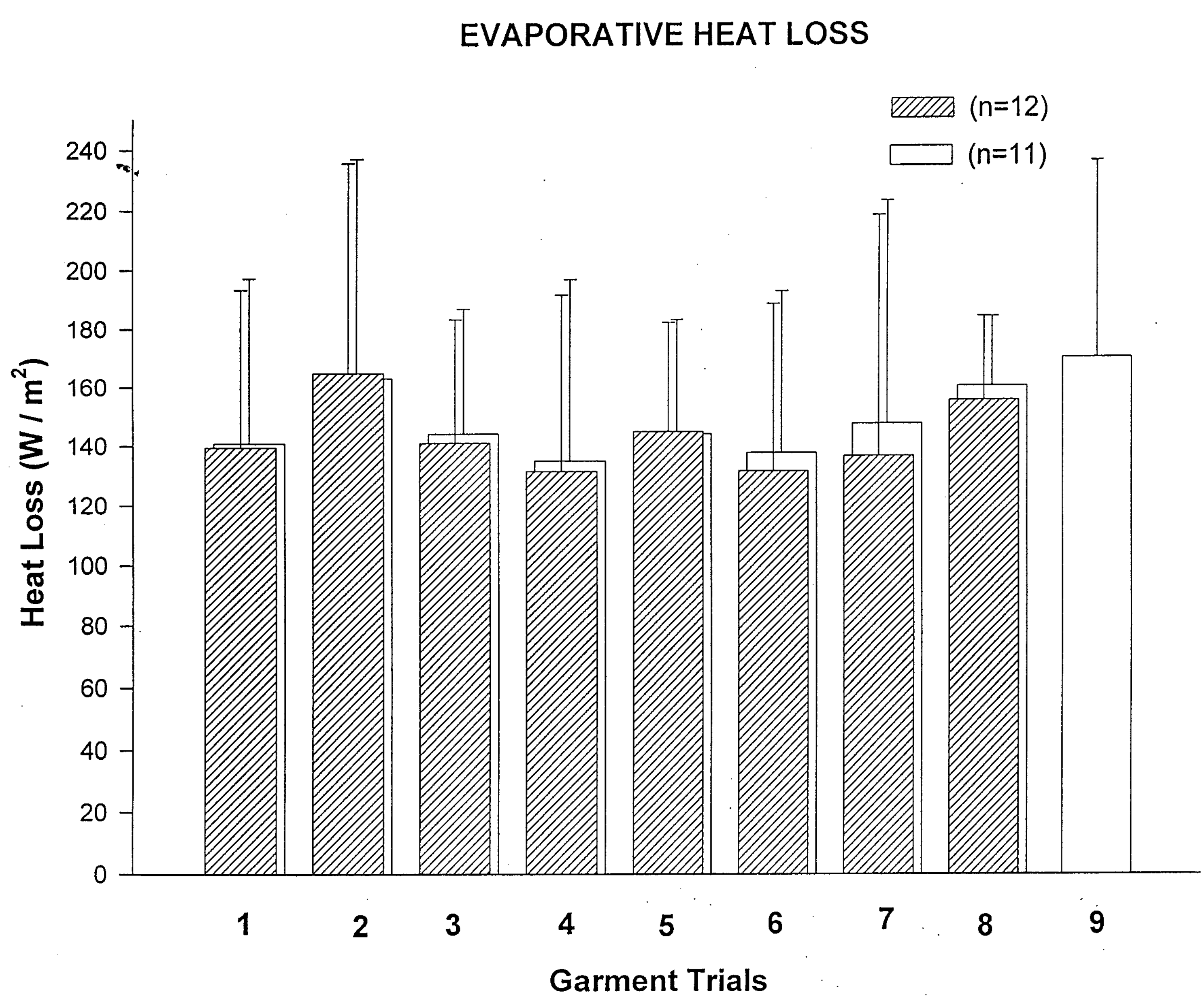

SWEATING RATE
Total SR
Evaporated SR
(n=11)
SR (g/min)
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
Garment Trials

Figure 8


EVAPORATIVE HEAT LOSS
(n=12)
(n=11)
Heat Loss (W / m2)
0
20
40
60
80
100
120
140
160
180
200
220
240
1
2
3
4
5
6
7
8
9
Garment Trials

Garment Trials 5 and 9

Test Time: (see Figure 2) Subjects in garment 9 walked significantly longer than they did in garment 5 (95 vs 79 min). This comparison was done with 11 subjects because one subject did not test in garment 9.

T_{re}: (see Figures 9a and 9b) For the 11 subjects who completed this trial, they were all still testing only to 50 min. In the 40-min analysis, from the beginning of the test, T_{re} for subjects in garment 5 was significantly higher than for those in garment 9. This significance was consistent when data through 65 min were analyzed (n=9). In both trails 5 and 9, T_{re} increased significantly over time throughout the test.

Insert Figures 9a and 9b here

Figure 9a

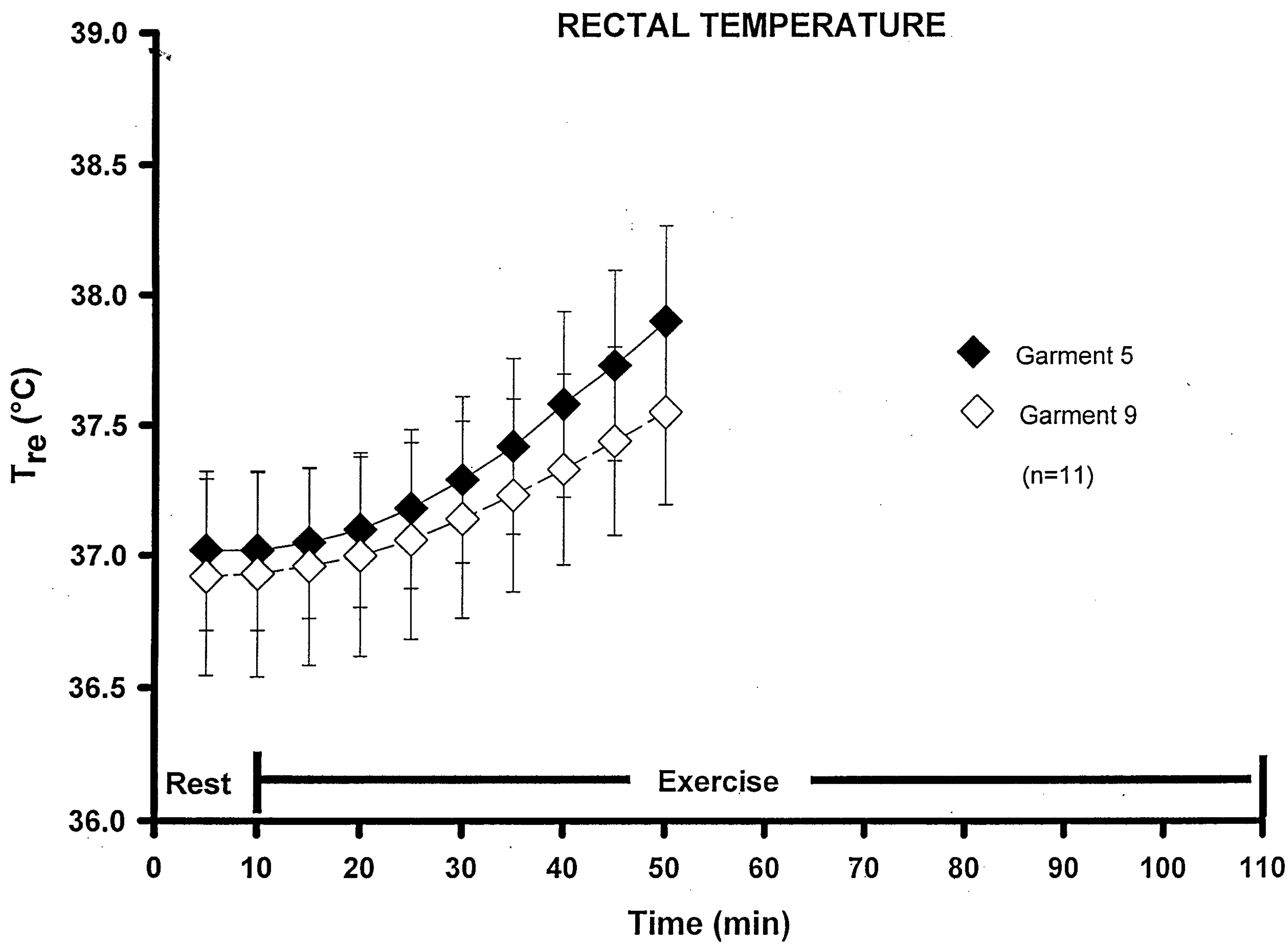
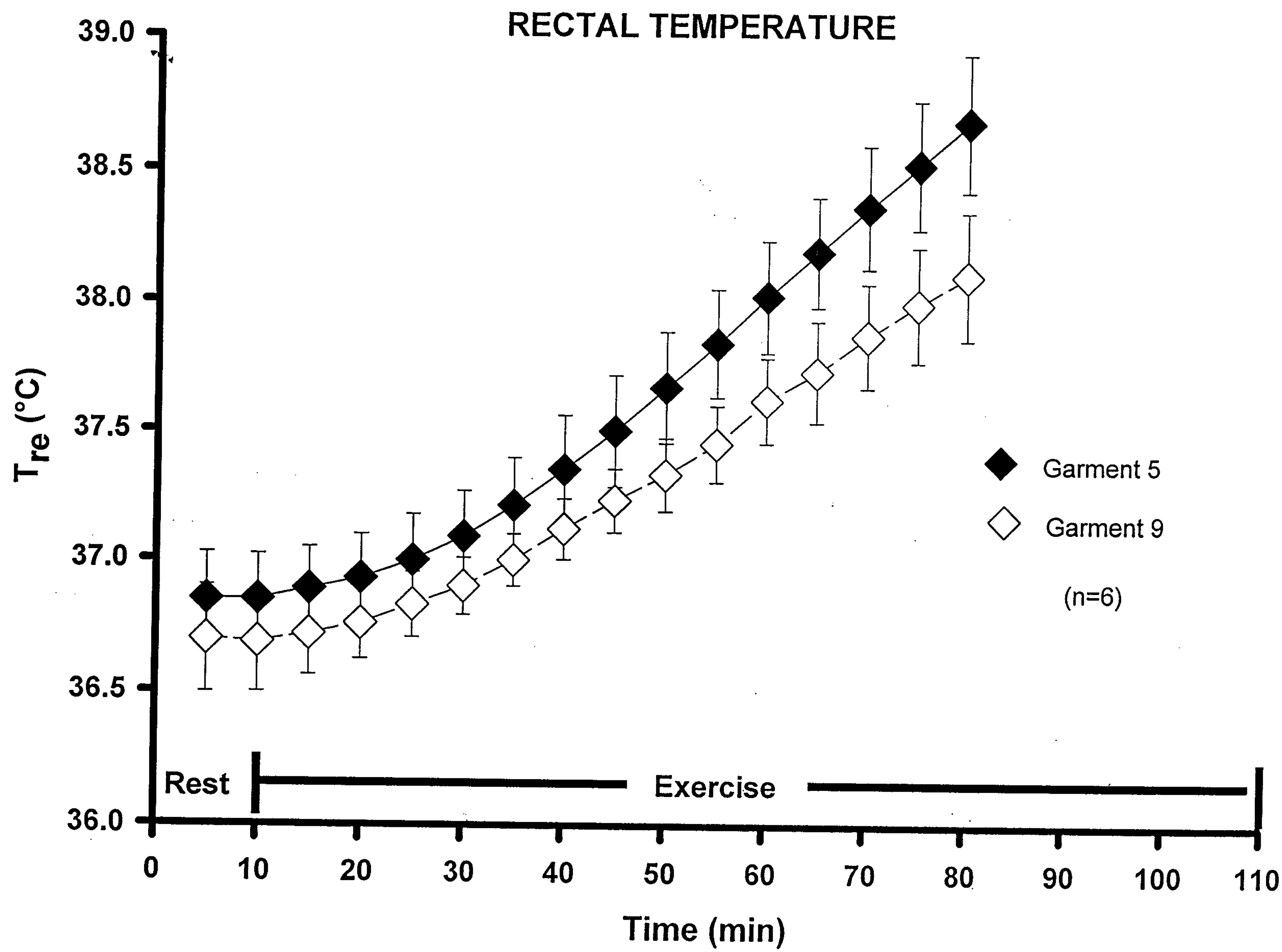

RECTAL TEMPERATURE
T_{re} (°C)
39.0
38.5
38.0
37.5
37.0
36.5
36.0
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Rest
Exercise
Garment 5
Garment 9
(n=11)

Figure 9b


RECTAL TEMPERATURE
T_{re} (°C)
39.0
38.5
38.0
37.5
37.0
36.5
36.0
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Garment 5
Garment 9
(n=6)

Delta T_{re}: (see Figures 10a and 10b) In the analysis to 50 min (n=11), from min 30 through 50 ΔT_{re} was significantly greater in garment 5. This difference continued in analyses to 65 min (n=9) and to 80 min (n=6), though the significance showed up later in these analyses (by min 40 and 50 respectively. ΔT_{re} increased over time in both trials.

Insert Figures 10a and 10b here

Figure 10a

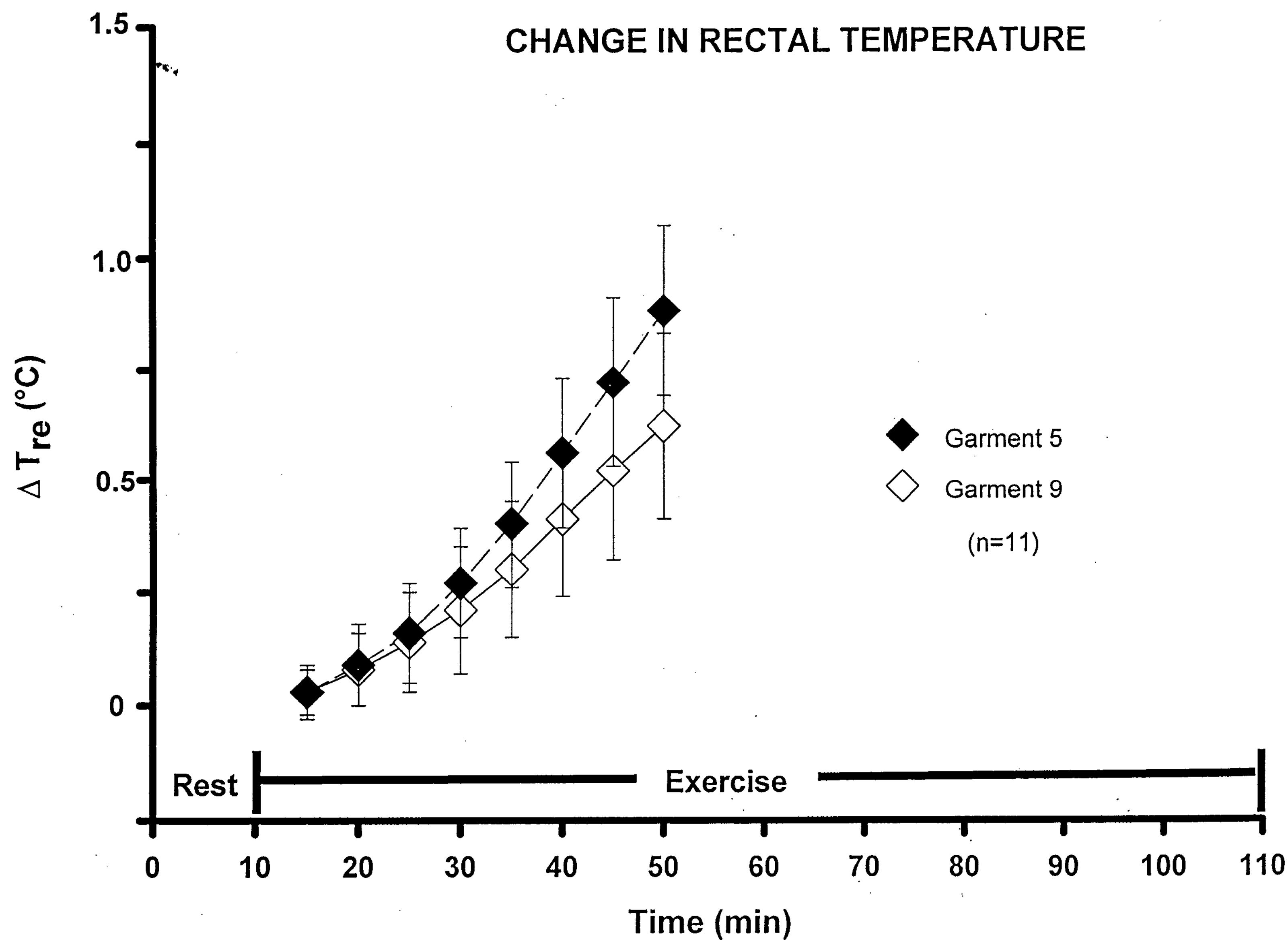
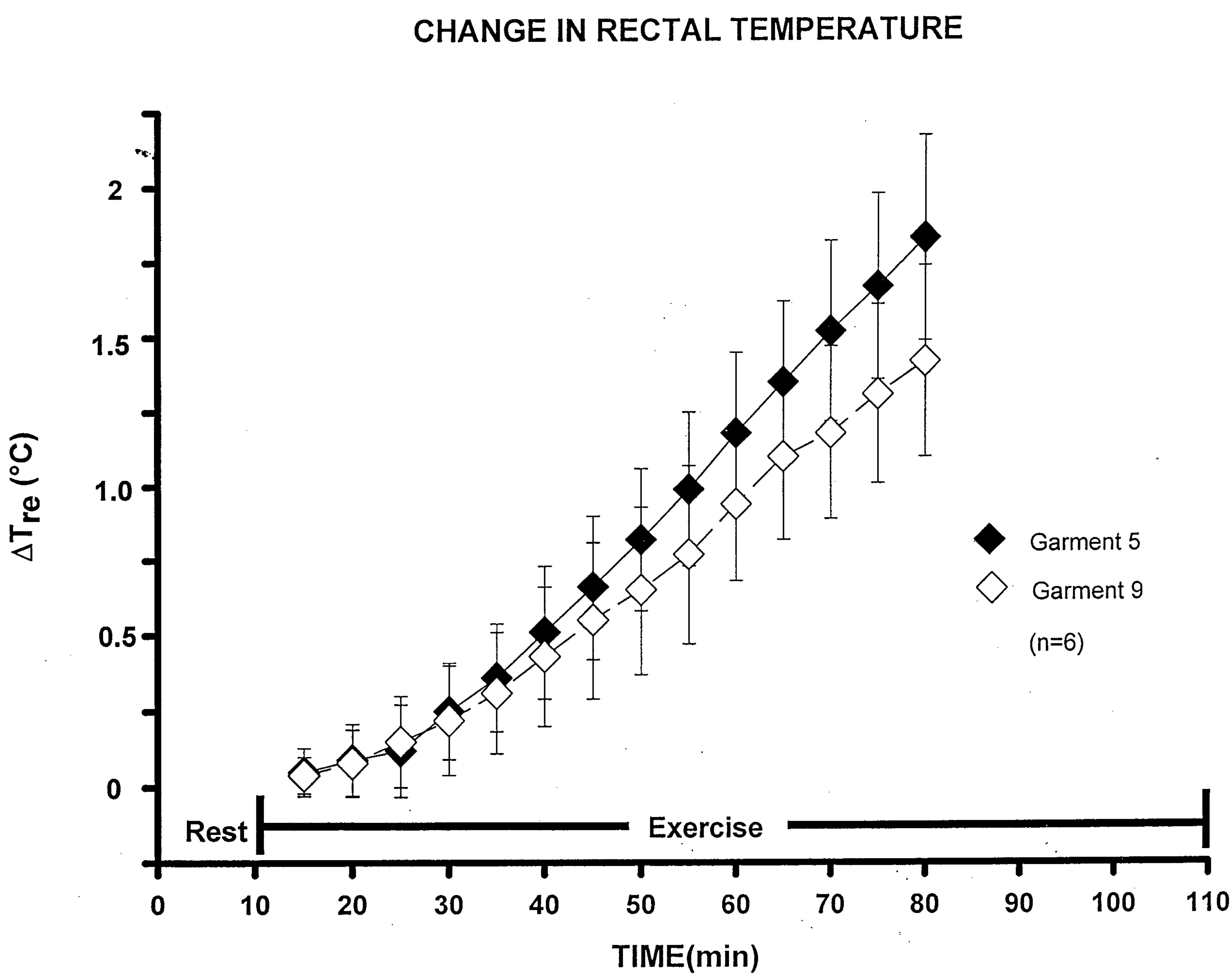

CHANGE IN RECTAL TEMPERATURE
Δ T_re (°C)
1.5
1.0
0.5
0
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Garment 5
Garment 9
(n=11)

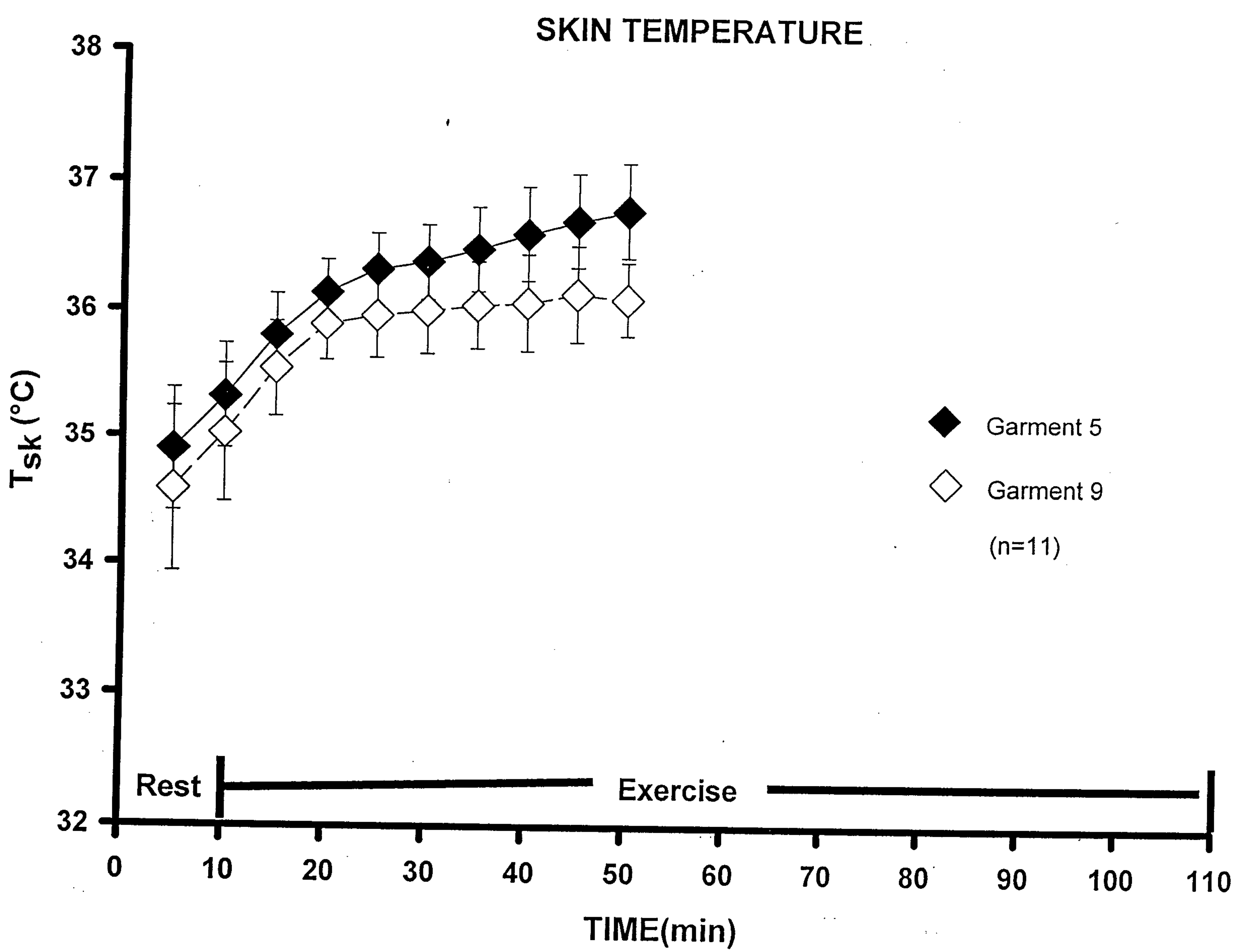
Figure 10b


CHANGE IN RECTAL TEMPERATURE
ΔTre (°C)
2
1.5
1.0
0.5
0
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
TIME(min)
Garment 5
Garment 9
(n=6)

$\bar{T}_{sk}$: (see Figures 11a and 11b) In the analysis to 50 min (n=11), from 25 through 50 min $\bar{T}_{sk}$ was significantly higher in garment 5. In the analysis to 80 min (n=6), the difference began at 35 min and continued through 80 min. $\bar{T}_{sk}$ increased over time throughout testing in garment 5, but plateaued during exercise in garment 9.

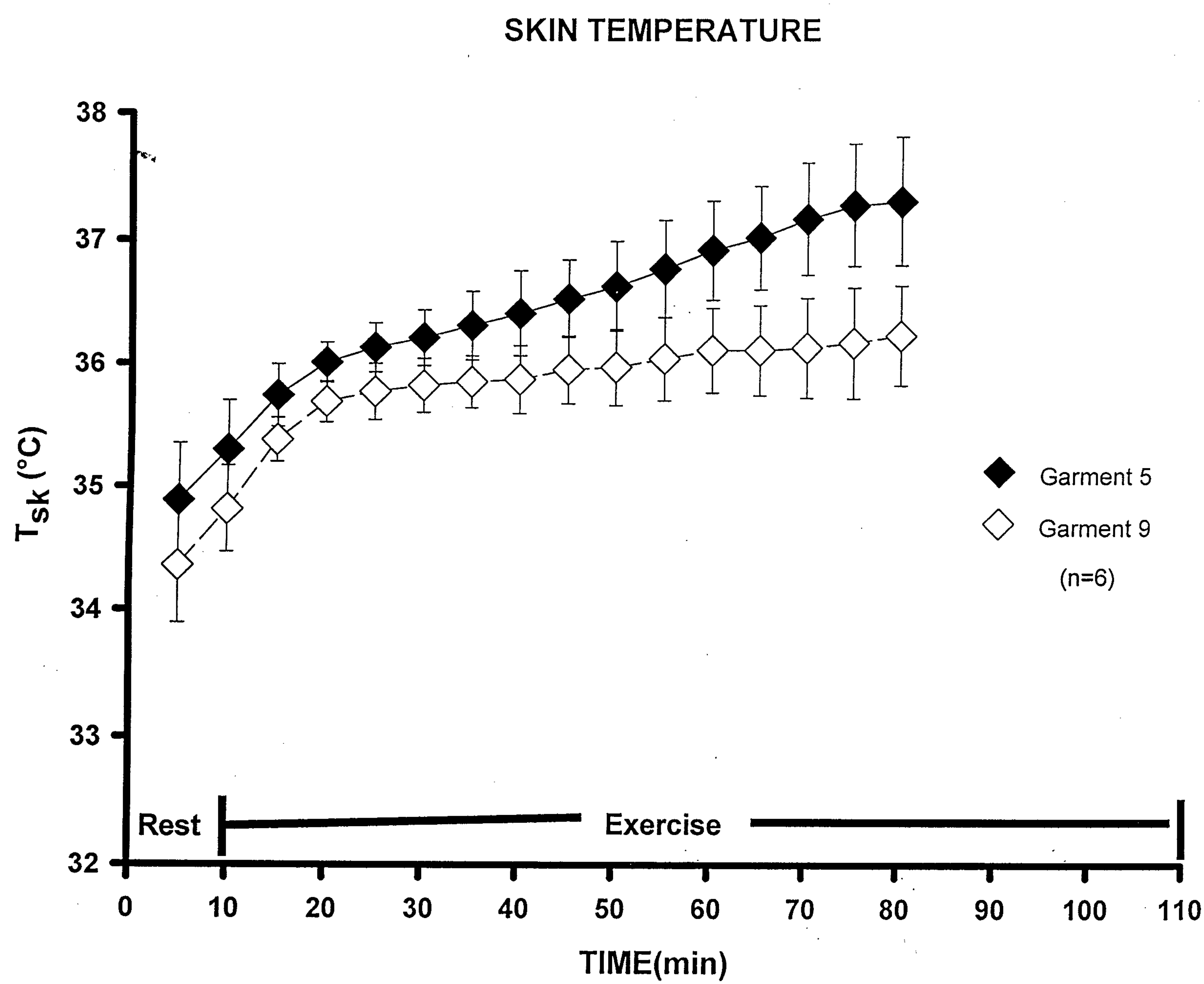
Insert Figures 11a and 11b here

Figure 11a



SKIN TEMPERATURE
Tsk (°C)
38
37
36
35
34
33
32
0
10
20
30
40
50
60
70
80
90
100
110
TIME(min)
Rest
Exercise
Garment 5
Garment 9
(n=11)

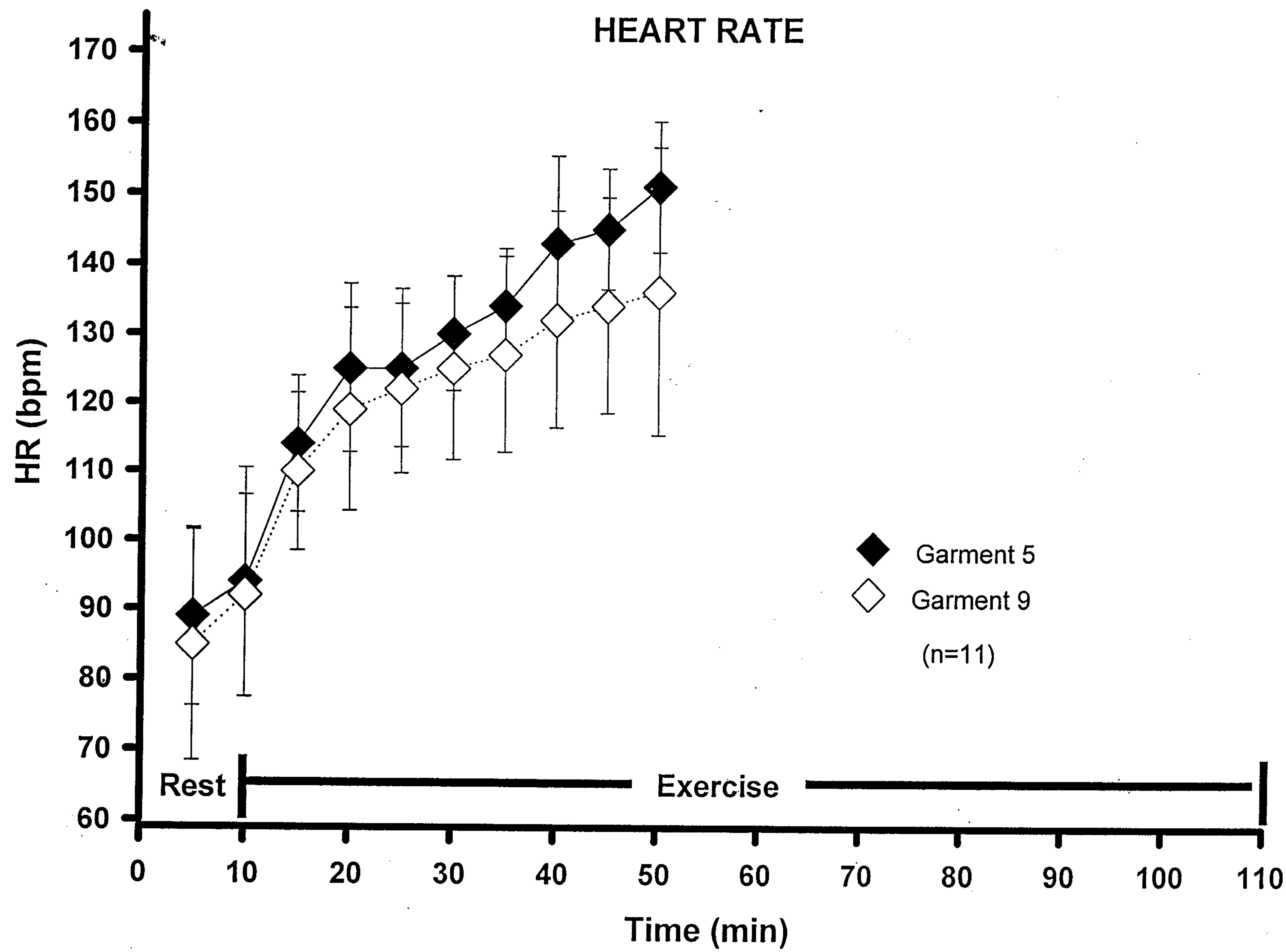
Figure 11b


SKIN TEMPERATURE
T_{sk} (°C)
38
37
36
35
34
33
32
0
10
20
30
40
50
60
70
80
90
100
110
TIME(min)
Rest
Exercise
Garment 5
Garment 9
(n=6)

Heart Rate: (see Figures 12a and 12b) For the 50 min analysis (n=11), heart rates increased significantly over time in both garment 5 and 9. By min 40 HR was significantly higher in garment 5. These differences continued to 80 min when data from 6 subjects were analyzed.

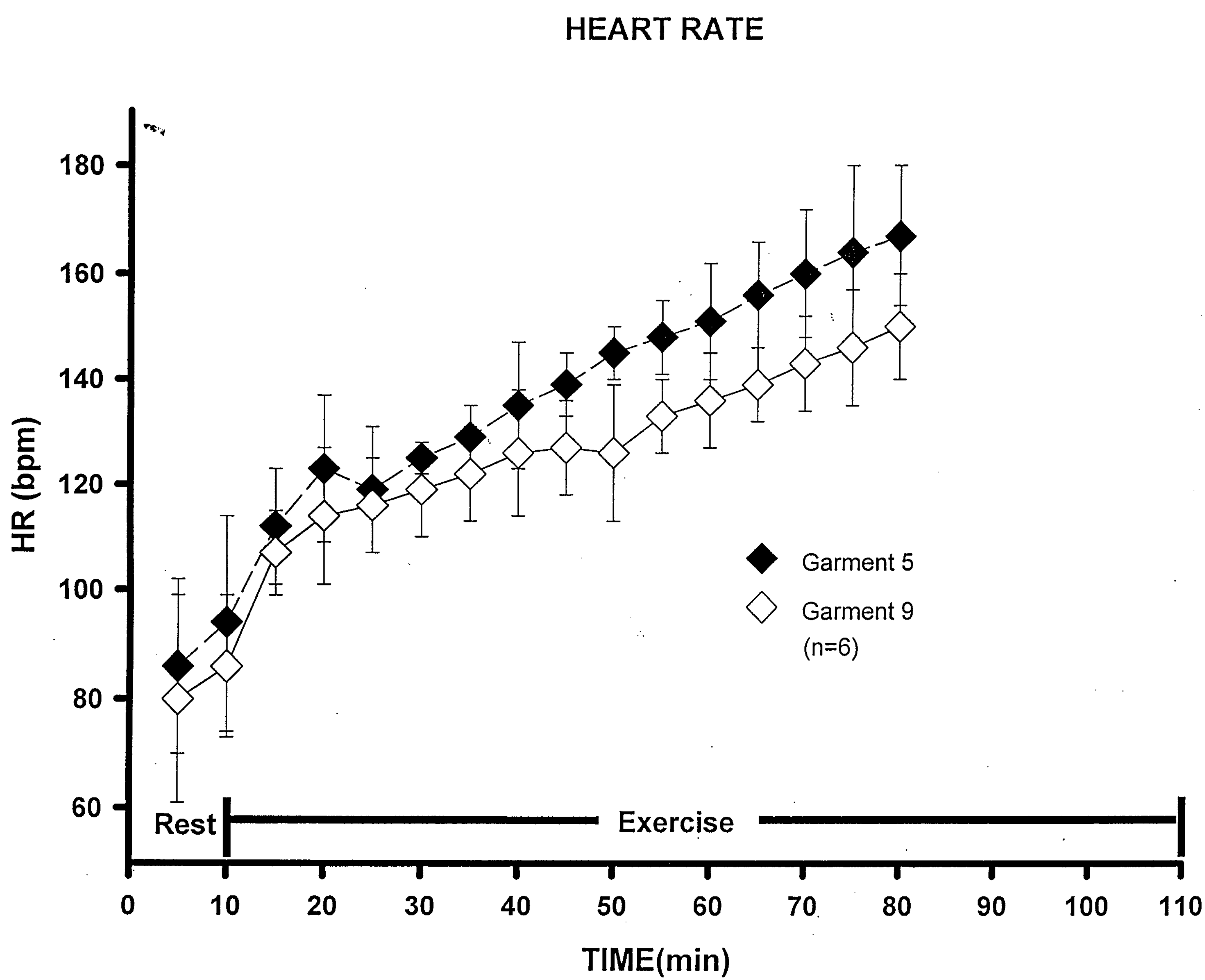
Insert Figures 12a and 12b here

Figure 12a



HEART RATE
HR (bpm)
170
160
150
140
130
120
110
100
90
80
70
60
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Garment 5
Garment 9
(n=11)

Figure 12b


HEART RATE
HR (bpm)
180
160
140
120
100
80
60
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
TIME(min)
Garment 5
Garment 9
(n=6)

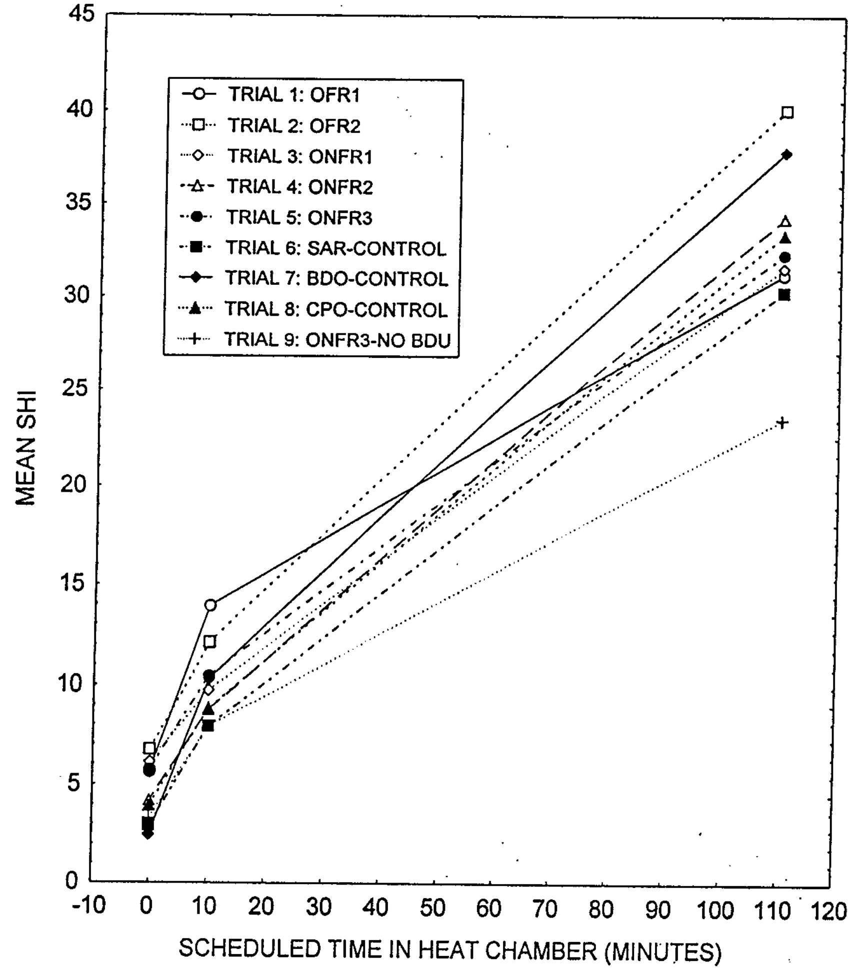
Sweating Rate and Evaporative Heat Loss: (see Figures 7 and 8). The total SR was greater for garment 5, but the % evaporated was greater in garment 9. Heat loss was not significantly different (p=0.15; 144 vs 170 $W \cdot m^{-2}$ for 5 and 9 respectively).

Subjective Data Comparisons among the first 9 test garments (n=11) were achieved by means of a 9 x 3 (garment x administration) repeated measures analysis of variance on the SHI scores. Post-hoc comparisons were made with the Newman-Keuls procedure. The results presented in Figure 13 show that when all 9 garments are compared with one another, there was a significant main effect of administration ($F(2,20)=40.60$; $p < 0.01$) indicating that the 100-minute-walk SHI mean scores (32.70 $\pm$ 18.0 s.d.) were significantly higher than either the pre-chamber (4.55 $\pm$ 5.4 s.d.) or the 10-minute-prewalk (9.98 $\pm$ 8.9 s.d.) scores which in turn did not differ from one another. There was a nonsignificant main effect for garment, $F(8,80)=1.63$; p=n.s. A significant garment x administration interaction ($F(16,160)=2.21$; $p < 0.01$) indicated that there was no significant difference among garments during the first two SHI administrations but that during the 100-minute-walk, Garments 2 (OFR2), 7 (BDO-Control), and 4 (ONFR2) led to the severest SHI scores, and Garment 9 (ONFR3-No BDU) was significantly less stressful subjectively than any of the other eight garments. While BDO-Control was ranked second to OFR2 in subjective heat stress, it was significantly more stressful than only Garment 6 (SAR-Control) and Garment 9 (ONFR3-No BDU). Garment 2 (OFR2), however, was judged significantly more stressful than all but BDO-Control and ONFR2. Garments 1, 3, 4, 5, and 8 (OFR1, ONFR1, ONFR2, ONFR3, and CPO-Control, respectively) were neither significantly different from one another nor from the BDO Control. In Figure 14, the SHI means are plotted with the abscissa indicating the actual median times spent in the chamber (prior to withdrawal); this plot shows that not only did Garment 9 impose the least amount of subjective heat stress but it permitted the most amount of time to be spent in the chamber prior to withdrawal. Likewise, it shows that not only did Garments 2, 7, and 4 impose the most subjective heat stress but also severely limited the amount of time the volunteers could spend in the chamber prior to withdrawal. Figure 15 clarifies these differences by boxing in the garments which do not differ from one another on SHI during the 100-minute-walk.

Insert Figure 13 here

Figure 13

Plot of SHI Means by Scheduled Time in Chamber
2-way interaction
$F(16,160)=2.21; p<.0068$



Insert Figures 14 and 15 here

Figure 14

Plot of SHI Means by Actual Time in Chamber
2-way interaction
$F(16,160)=2.21; p<.0068$

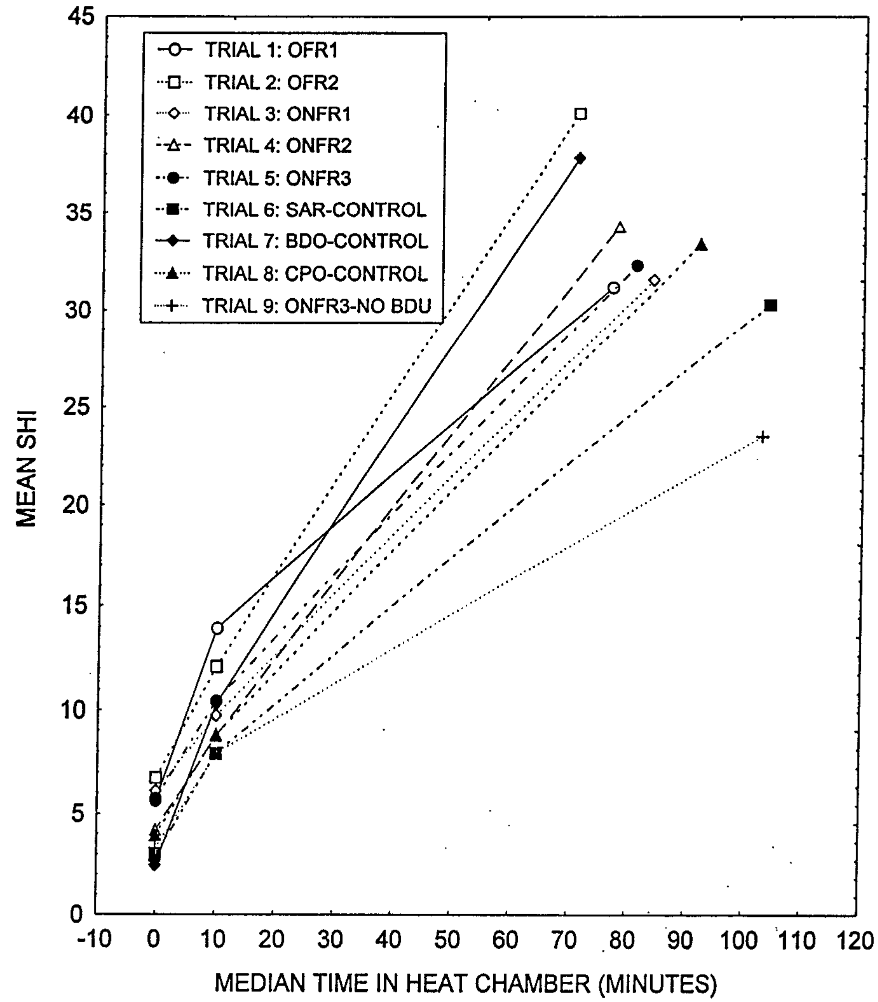
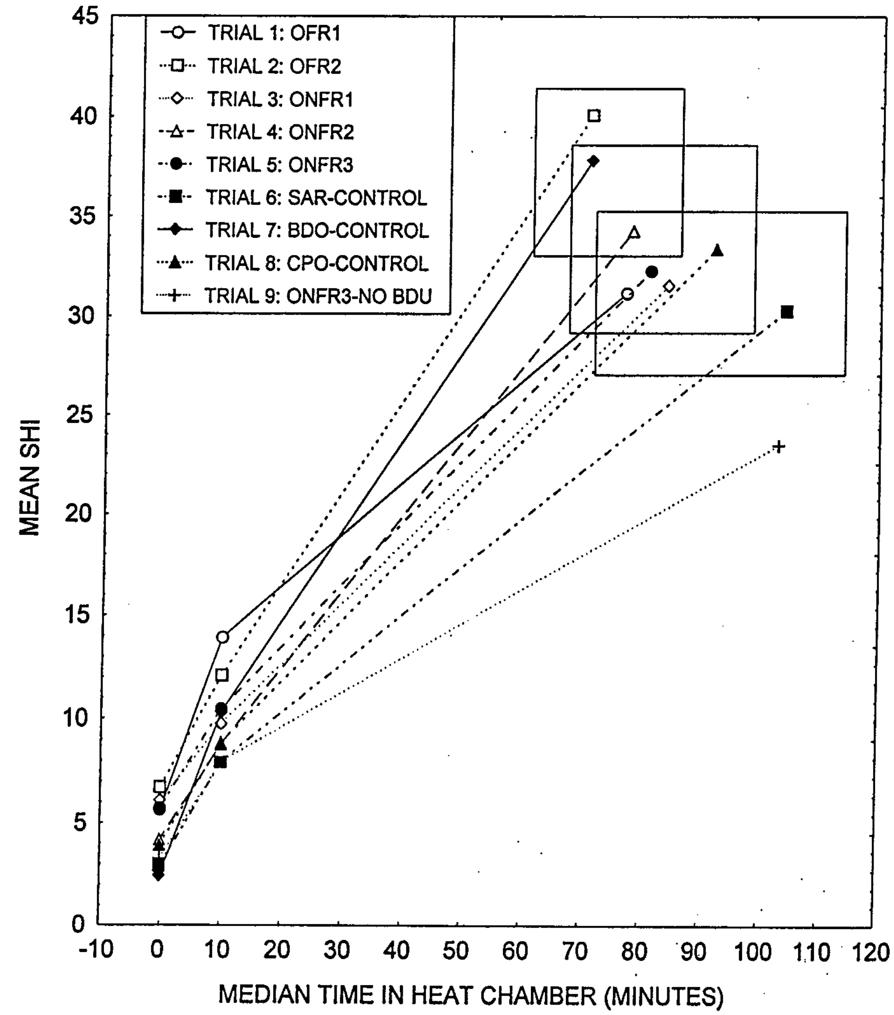


Figure 15

Post Hoc Test Results for 100-Minute-Walk
Symbols Sharing a Box Do Not Differ on SHI
by Newman-Keuls Tests

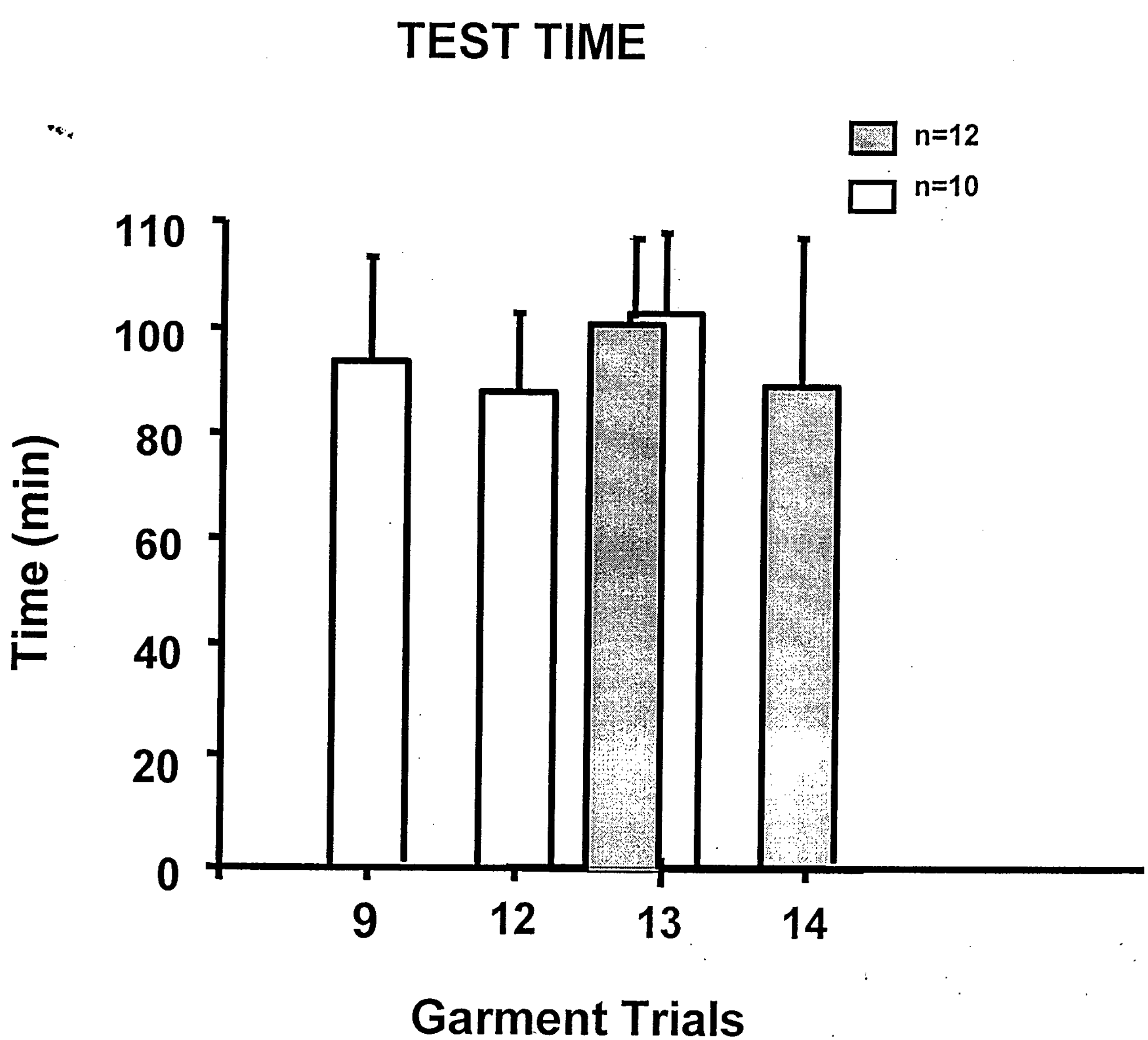


Garment Trials 9 and 12

Test Time: (see Figure 16) Test time was not significantly different between garments 9 and 12 (n= 10; 94 vs 88 min). (The 9 vs 12 analyses include 10 subjects because 2 subjects did not complete trial 12.)

Insert Figure 16 here

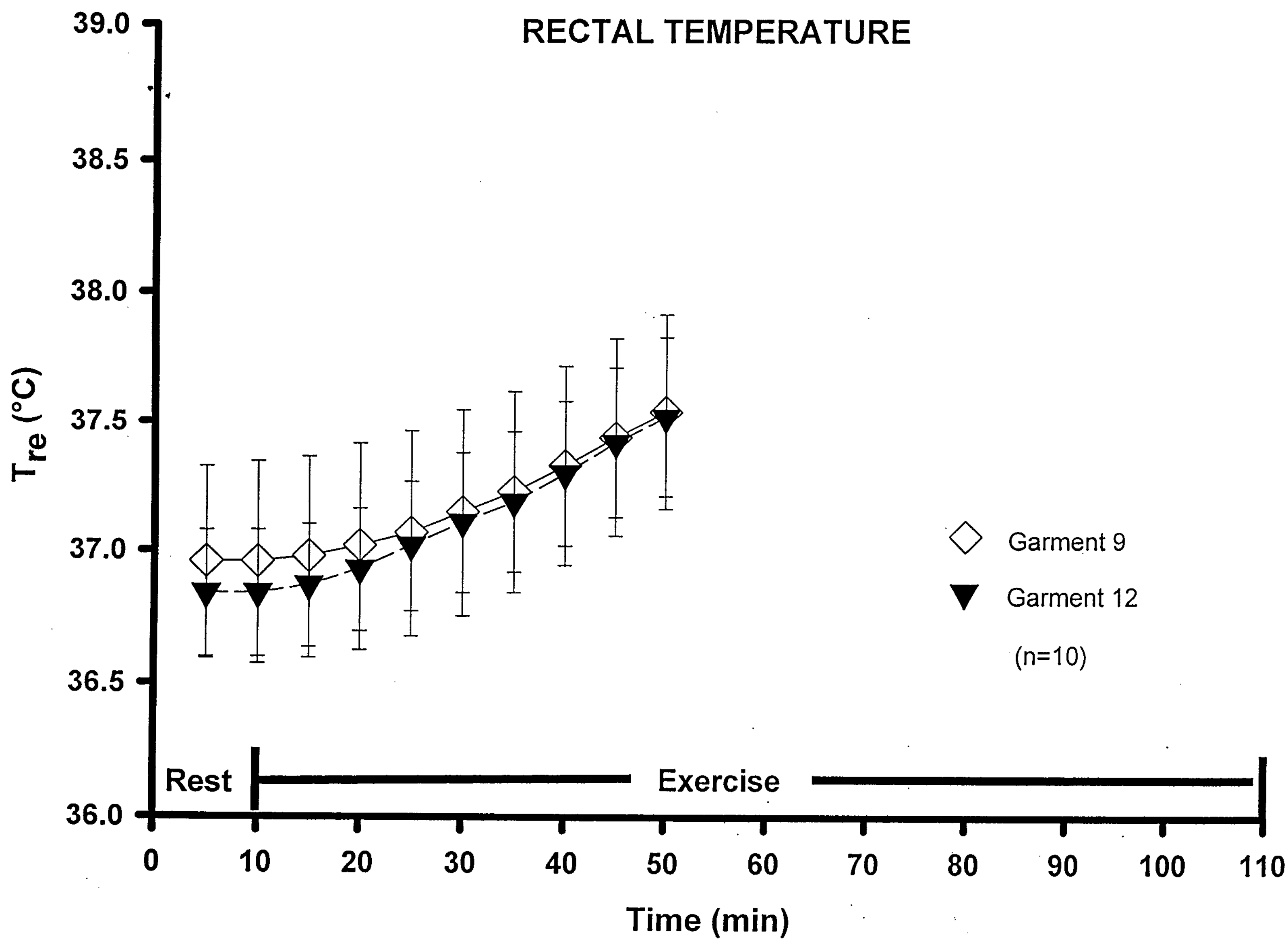
Figure 16


TEST TIME
n=12
n=10
110
100
80
60
40
20
0
Time (min)
9
12
13
14
Garment Trials

T_{re}: (see Figures 17a-b) In analysis to 50 min (n=10) there were no significant differences between garments. Both increased over time at about the same rate. In analysis to 80 min (n=8), the garments were also not significantly different with regard to T_{re}.

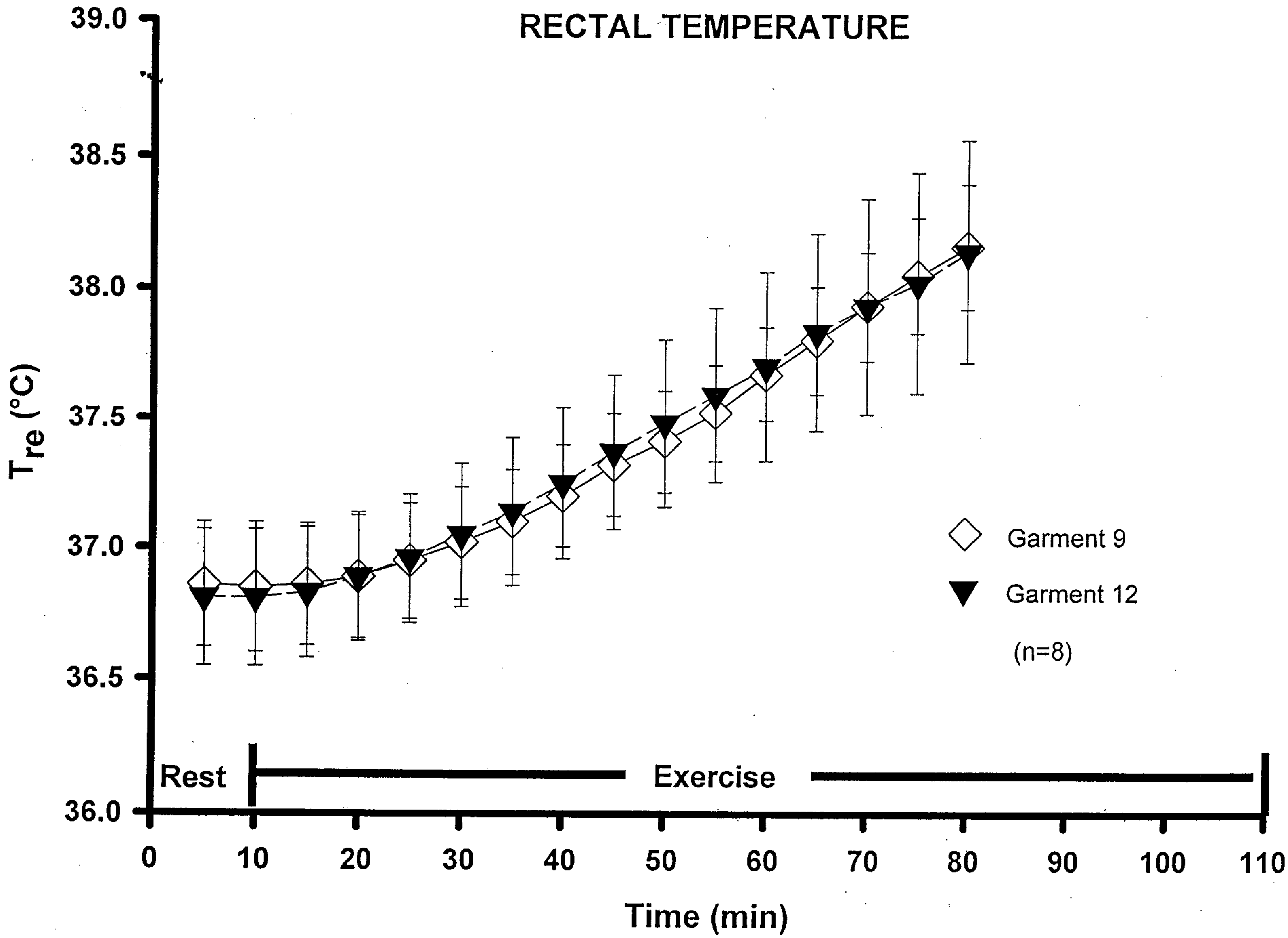
Insert Figures 17a and 17b here

Figure 17a



RECTAL TEMPERATURE
Tre (°C)
39.0
38.5
38.0
37.5
37.0
36.5
36.0
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Garment 9
Garment 12
(n=10)

Figure 17b


RECTAL TEMPERATURE
Tre (°C)
39.0
38.5
38.0
37.5
37.0
36.5
36.0
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Rest
Exercise
Garment 9
Garment 12
(n=8)

Delta T_{re}: (see Figures 18a-b) When ΔT_{re} was analyzed to 50 min (n=10), garment 12 elicited greater changes from min 25 through 50. In the 80 min comparison (n=8), the differences were not significant except at min 55 where ΔT_{re} in 12 was greater than in 9.

Insert Figures 18a and 18b here

Figure 18a

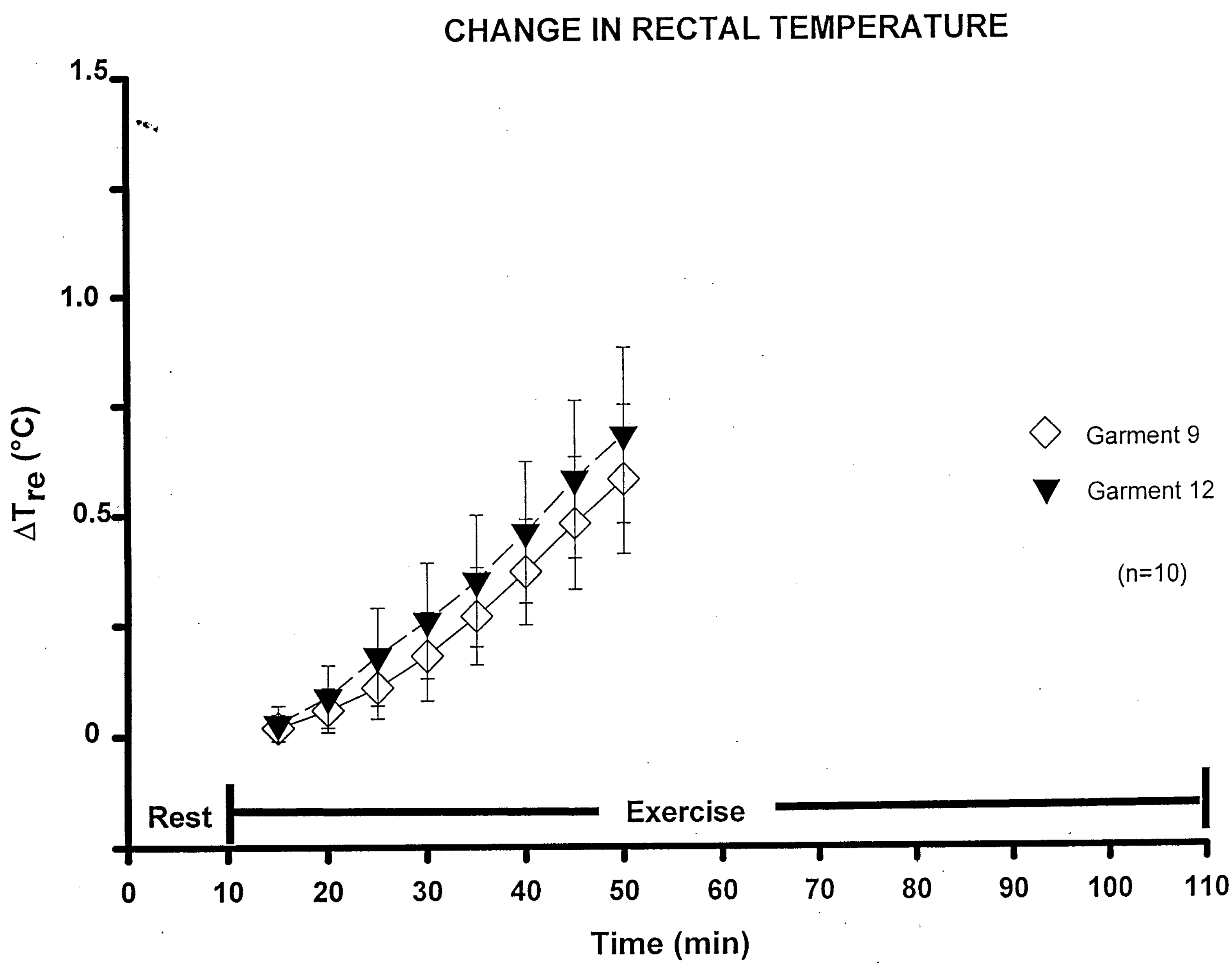
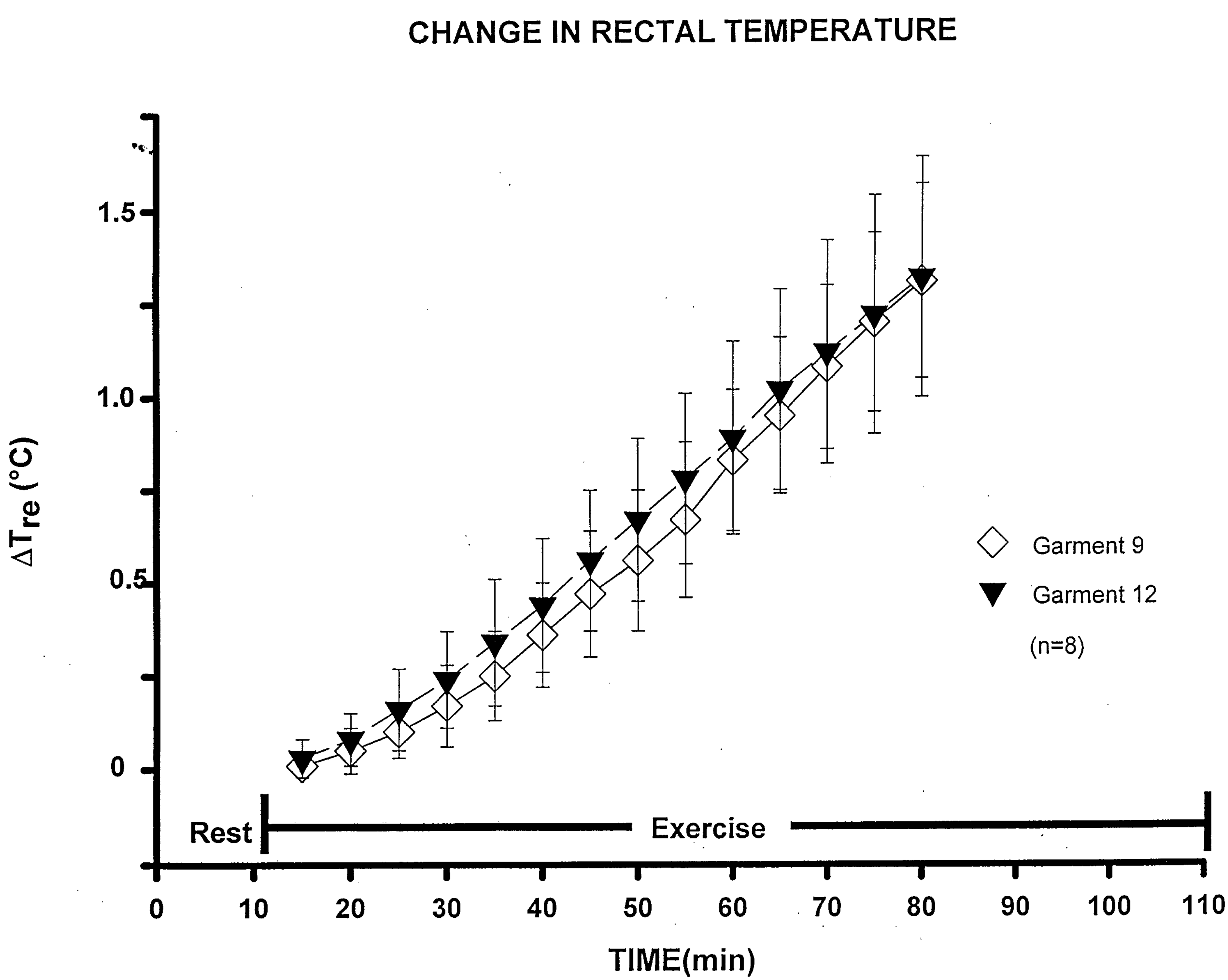

CHANGE IN RECTAL TEMPERATURE
ΔT_{re} (°C)
1.5
1.0
0.5
0
Garment 9
Garment 12
(n=10)
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)

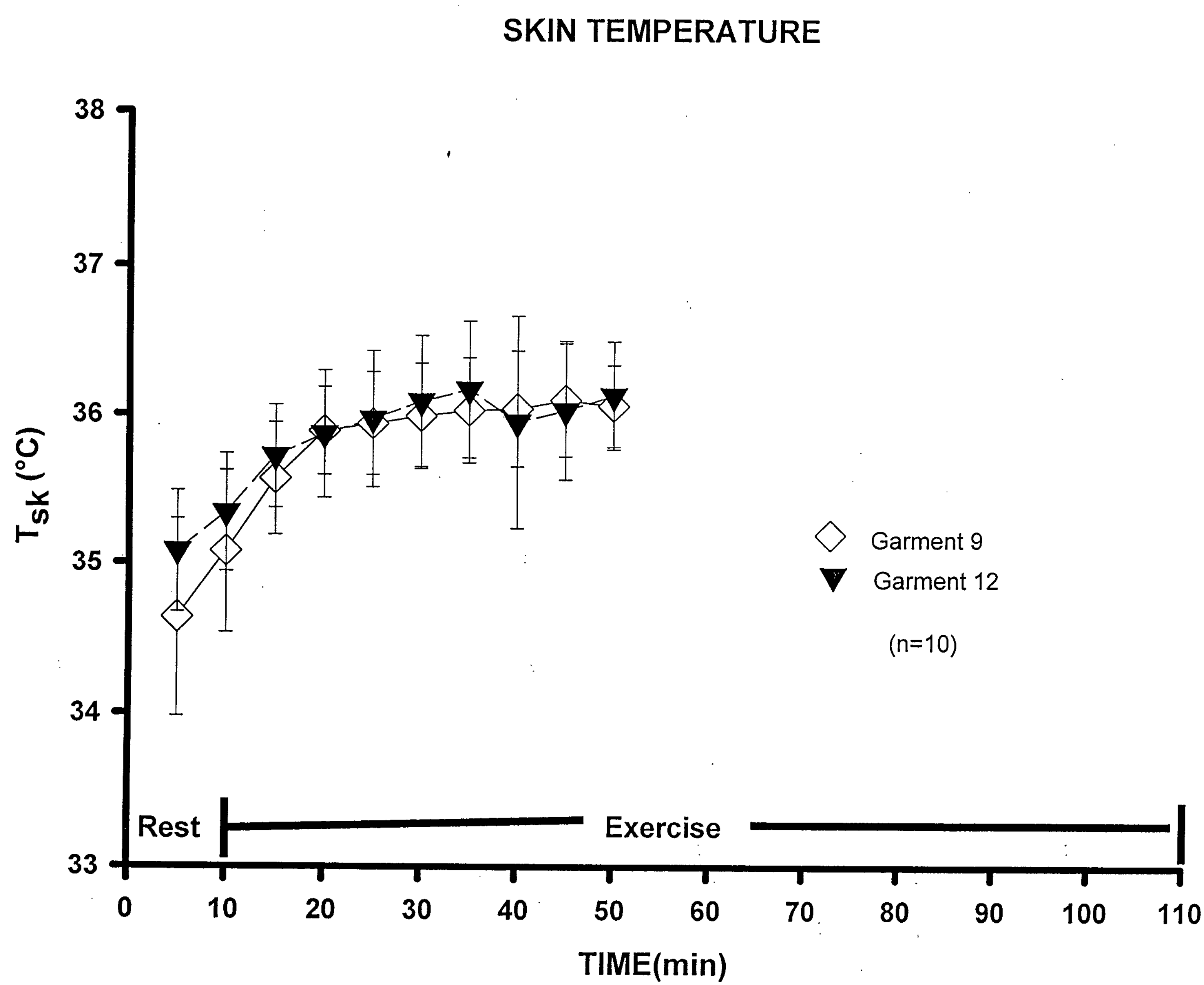
Figure 18b


CHANGE IN RECTAL TEMPERATURE
ΔT_{re} (°C)
0
0.5
1.0
1.5
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
TIME(min)
Garment 9
Garment 12
(n=8)

$\bar{T}_{sk}$: (see Figures 19a-b) In neither the analysis to 50 min (n=10), nor in that to 80 min (n=8), were there significant differences in $\bar{T}_{sk}$. In both analyses, $\bar{T}_{sk}$ increased similarly over time.

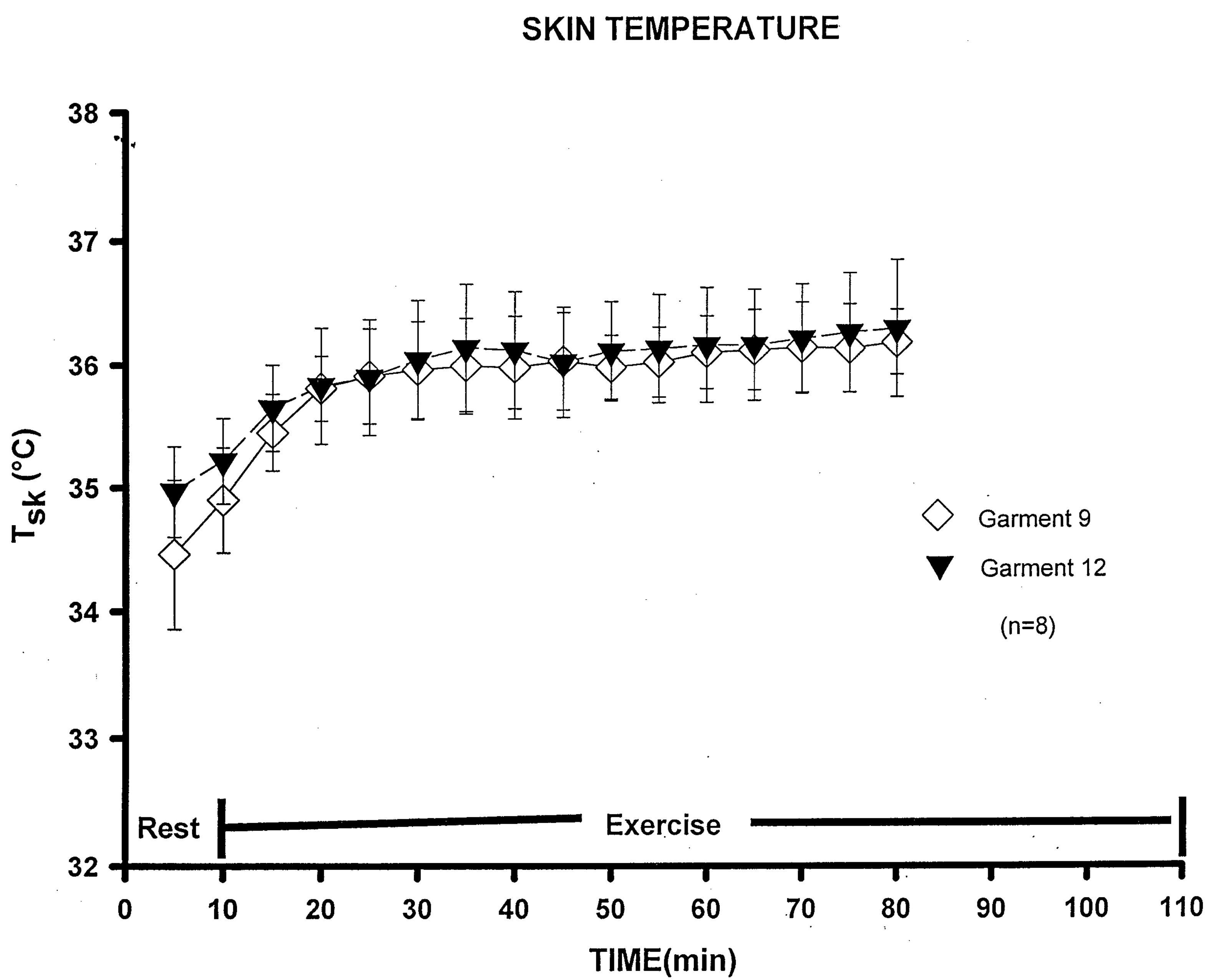
Insert Figures 19a and 19b here

Figure 19a



SKIN TEMPERATURE
T_{sk} (°C)
38
37
36
35
34
33
0
10
20
30
40
50
60
70
80
90
100
110
TIME(min)
Rest
Exercise
Garment 9
Garment 12
(n=10)

Figure 19b


SKIN TEMPERATURE
T_{sk} (°C)
38
37
36
35
34
33
32
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
TIME(min)
Garment 9
Garment 12
(n=8)

Heart Rate: (see Figures 20a-b) As with rectal and skin temperatures, HR was not different between garments in either the 50 or 80-min analyses, and in both analyses HR in both garments increased similarly over time.

Insert Figures 20a and 20b here

Figure 20a

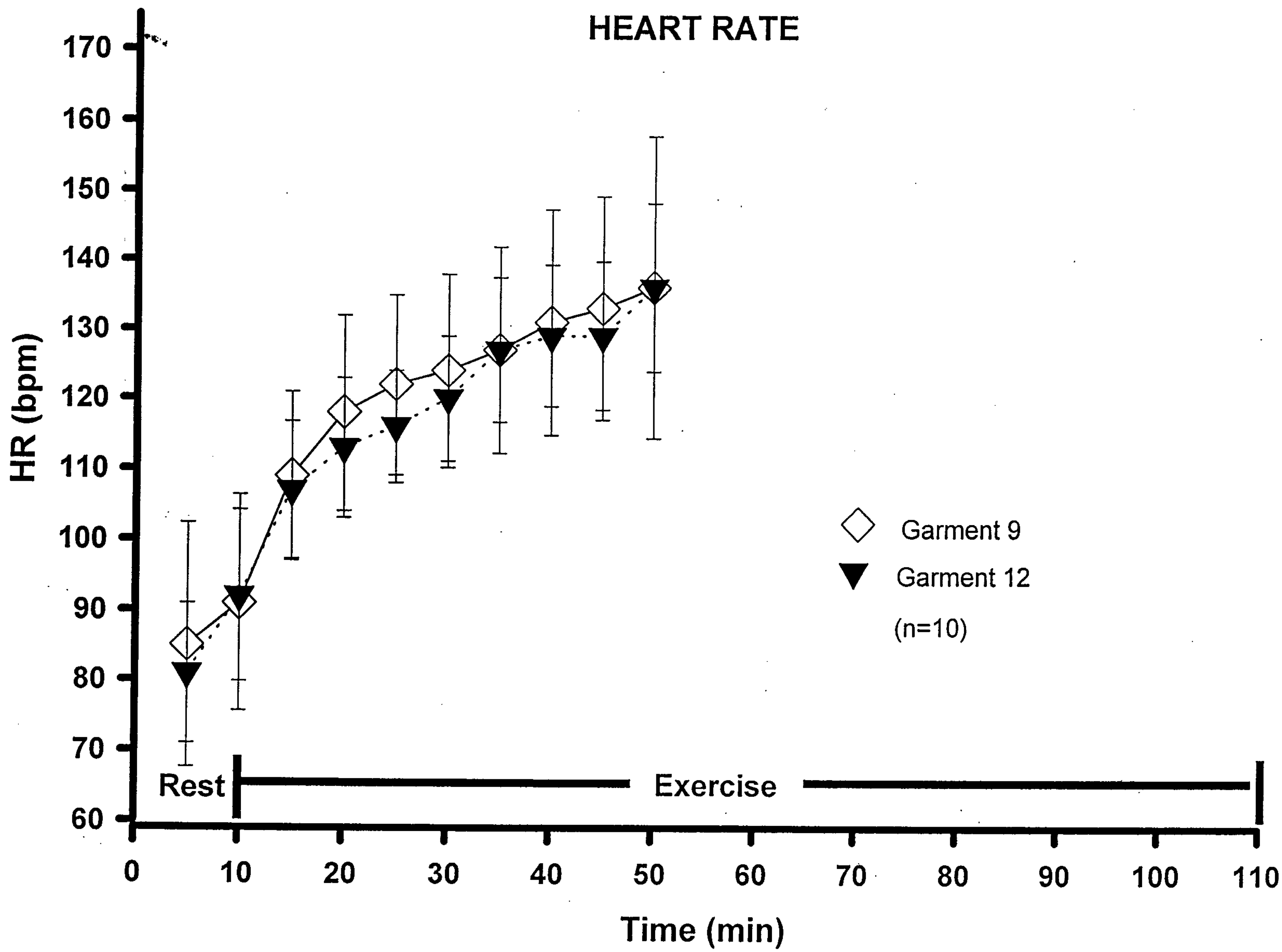
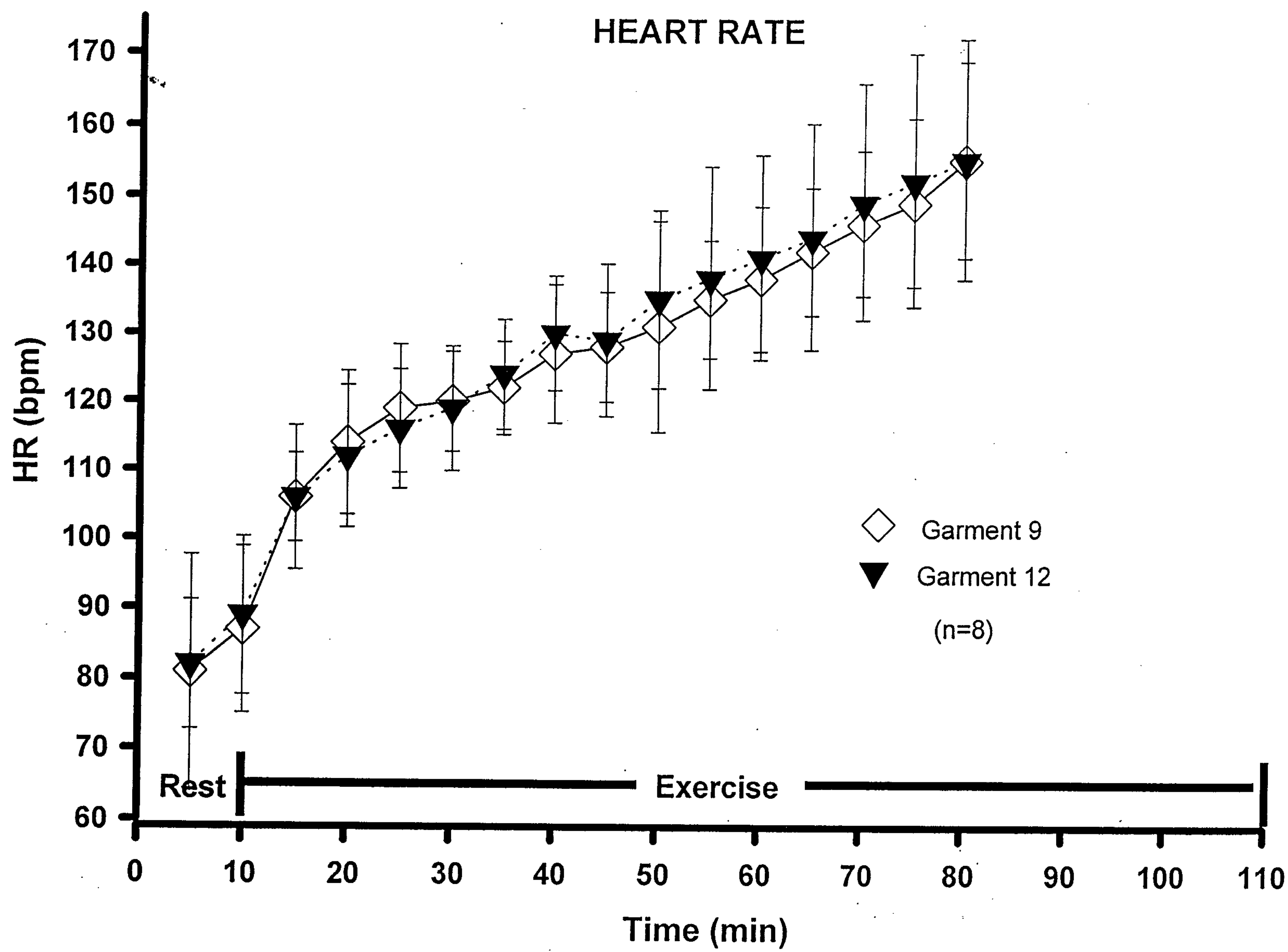

HEART RATE
HR (bpm)
170
160
150
140
130
120
110
100
90
80
70
60
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Rest
Exercise
Garment 9
Garment 12
(n=10)

Figure 20b


HEART RATE
HR (bpm)
170
160
150
140
130
120
110
100
90
80
70
60
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Rest
Exercise
Garment 9
Garment 12
(n=8)

Sweating Rate and Evaporative Heat Loss: (see Figures 21 and 22). Neither total sweating rate nor the % evaporated differed between garments 9 and 12. The heat loss also did not differ.

Insert Figures 21 and 22 here

Figure 21

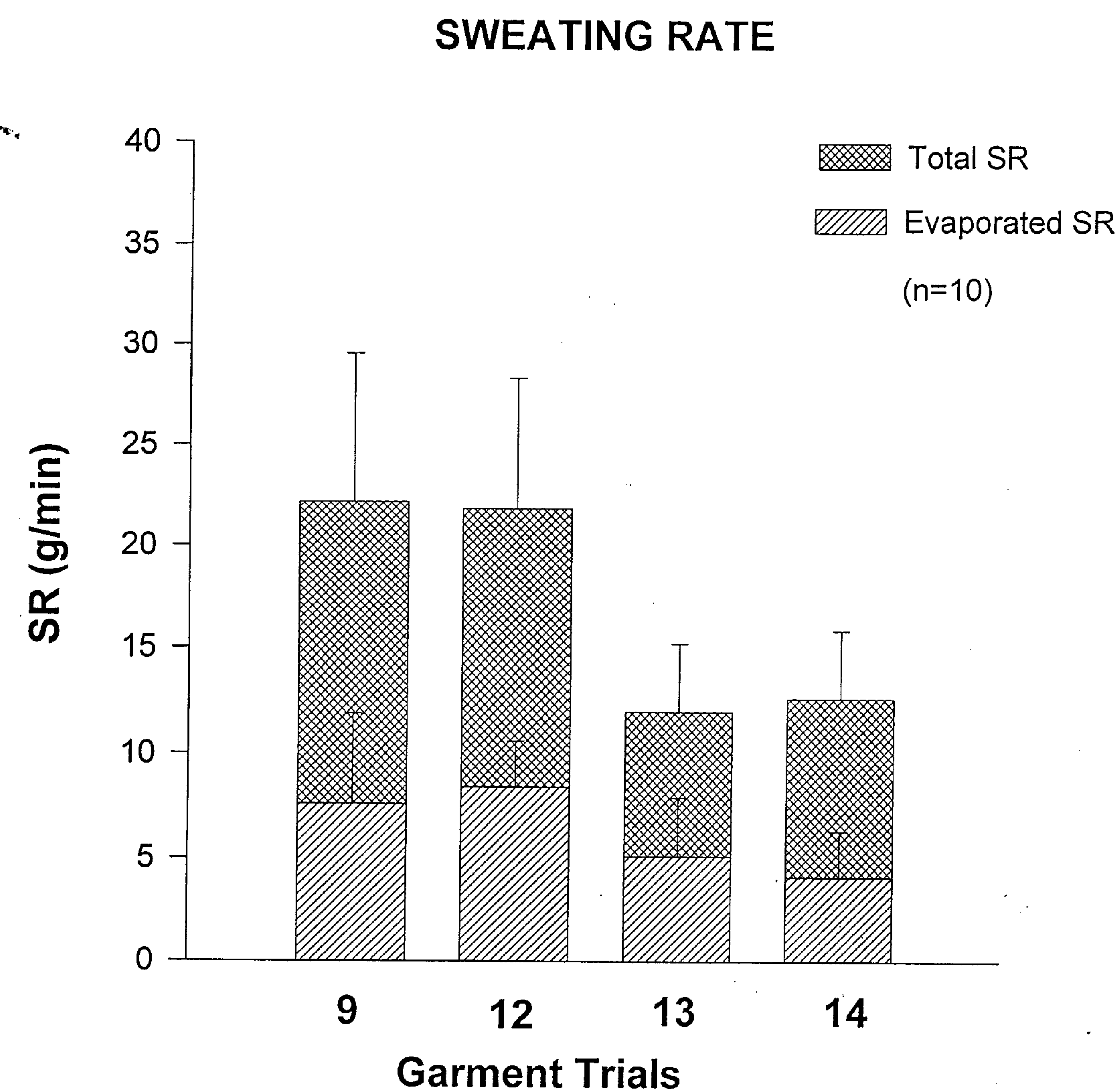
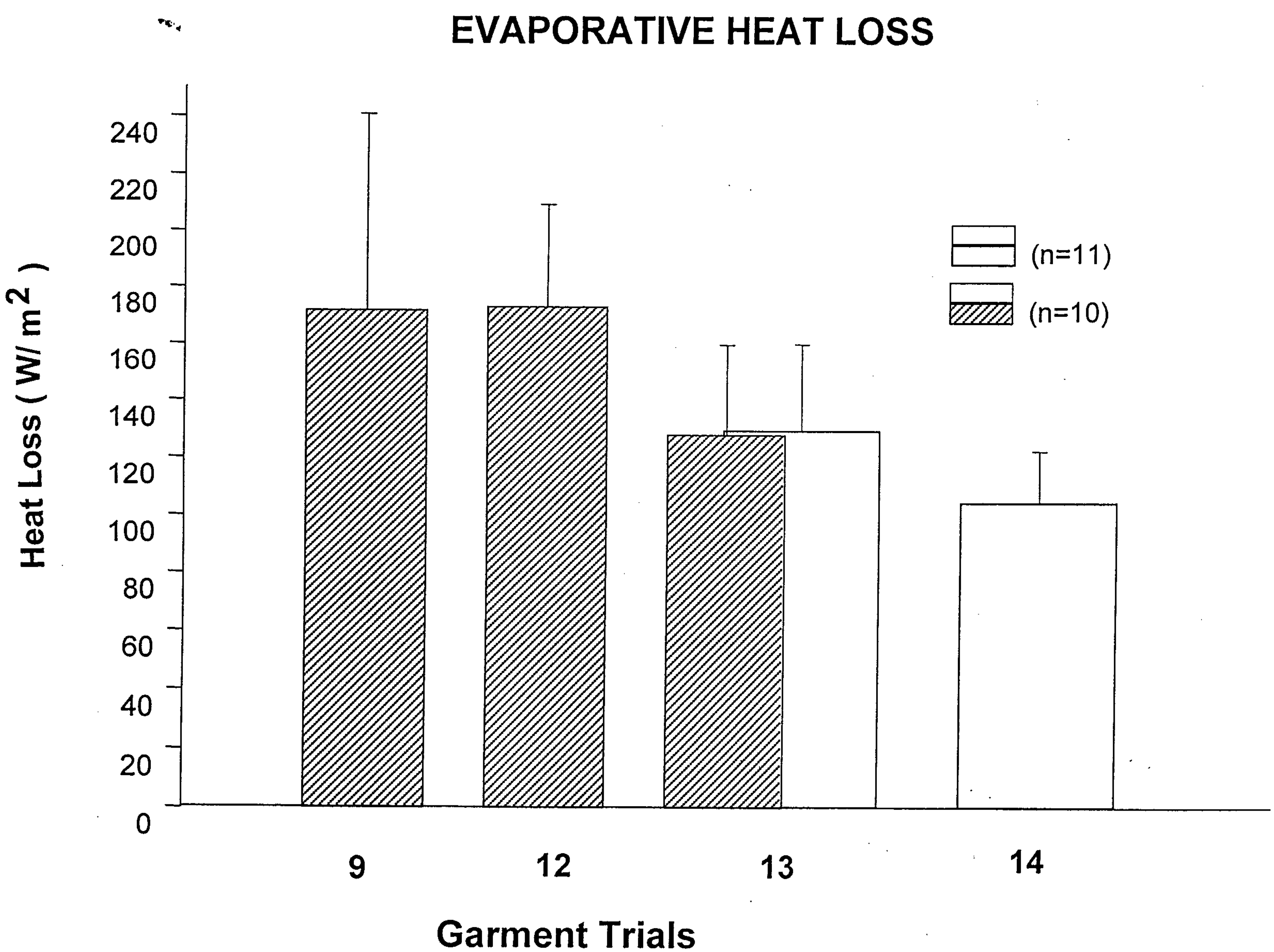

SWEATING RATE
Total SR
Evaporated SR
(n=10)
SR (g/min)
0
5
10
15
20
25
30
35
40
9
12
13
14
Garment Trials

Figure 22



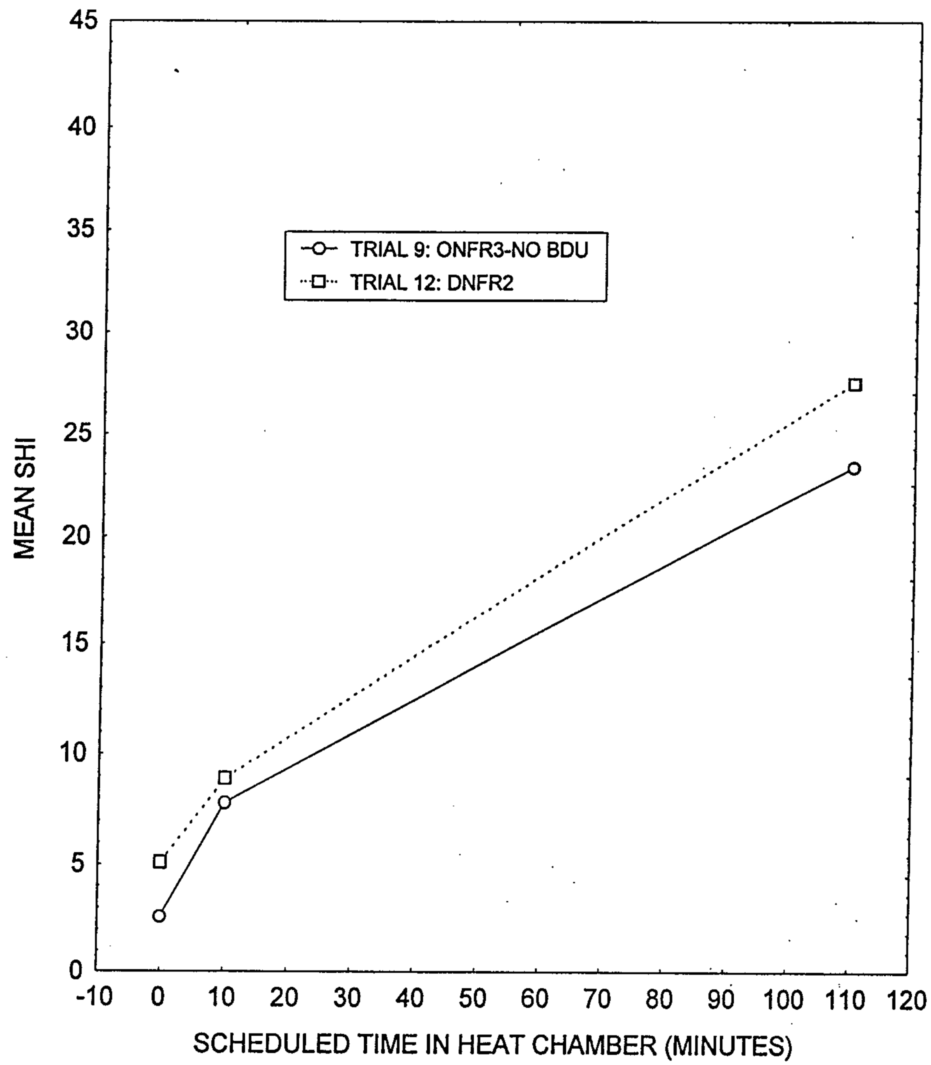
EVAPORATIVE HEAT LOSS
Heat Loss (W/ m2)
240
220
200
180
160
140
120
100
80
60
40
20
0
(n=11)
(n=10)
9
12
13
14
Garment Trials

Subjective Data Comparison of Garment Trial 9 (ONFR3-No BDU) and Garment Trial 12 (worst-case JSLIST-D-NFR2) (n=10): There was no significant difference in SHI mean scores between Garment Trial 9 (11.27 $\pm$ 13.19 s.d.) and Garment Trial 12 (13.83 $\pm$ 14.24 s.d.). However, for both garment trials, SHI scores were significantly higher ($F(2,18)=17.03$; $p < 0.01$) during the 100-minute-walk in 95° heat (25.45 $\pm$ 15.87 s.d.) as compared to SHI scores prior to entering the test chamber (3.85 $\pm$ 3.22 s.d.) or during the 10-minute-prewalk (8.35 $\pm$ 6.67 s.d.). There was no significant garment x administration interaction. See Figure 23.

Insert Figure 23 here

Figure 23

Plot of SHI Means by Scheduled Time in Chamber
2-way interaction (non-significant)
Time in Chamber by Garment

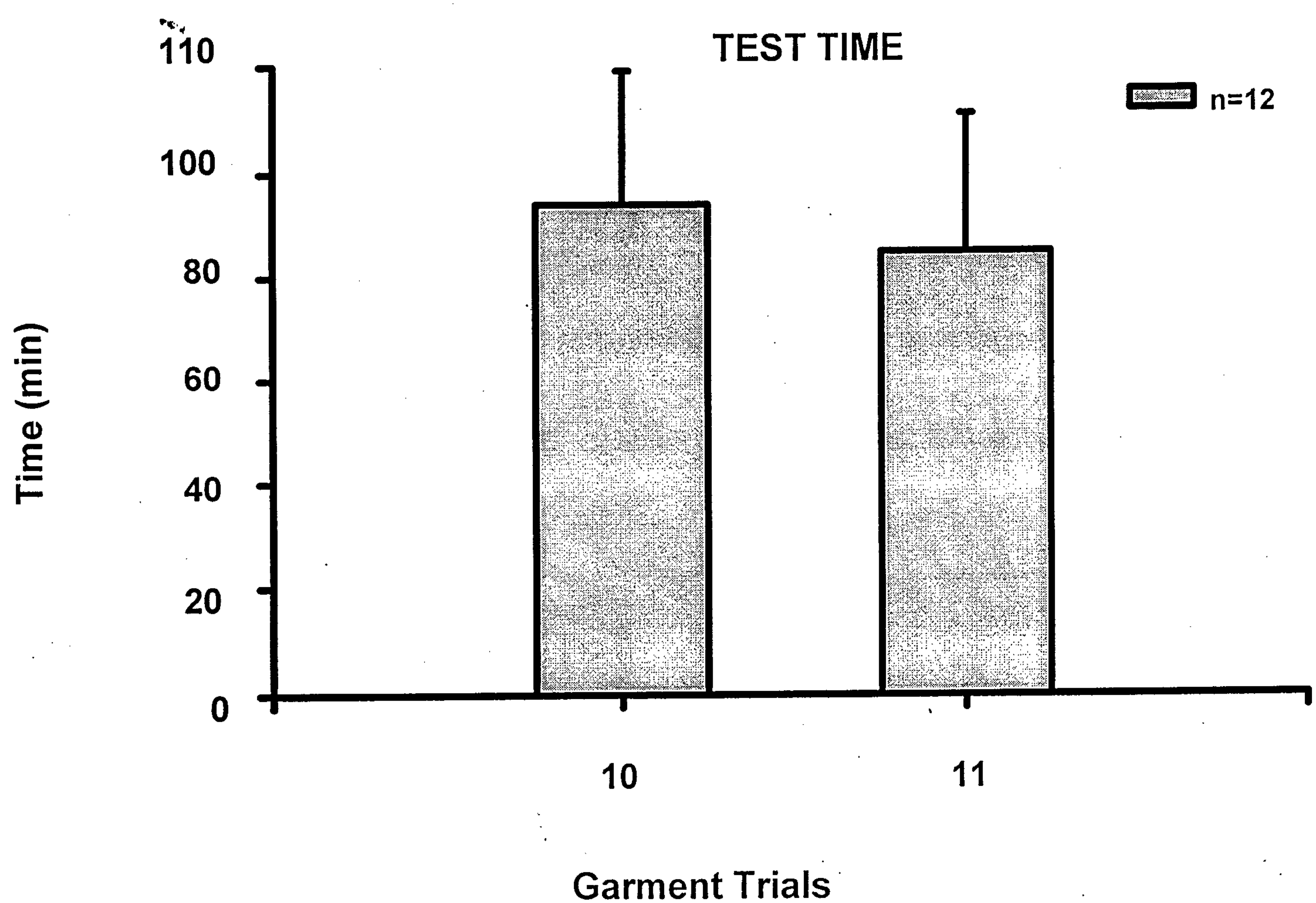


Garment Trials 10 and 11

Test Time: (see Figure 24) Test time did not differ significantly between garments 10 (94 min) and 11 (85 min).

Insert Figure 24 here

Figure 24


TEST TIME
n=12
Time (min)
110
100
80
60
40
20
0
10
11
Garment Trials

T_{re}: (see Figures 25a-b) Because of very short test times, data from one subject was eliminated from the analysis. In the analysis to 60 min (n=11), from min 35 through min 60, T_{re} were higher during garment 11 trials. These differences continued in the analysis to 90 min (n=6), where differences became more pronounced as the test progressed. In each analysis, T_{re} increased over time for both garments.

Insert Figures 25a and 25b here

Figure 25a

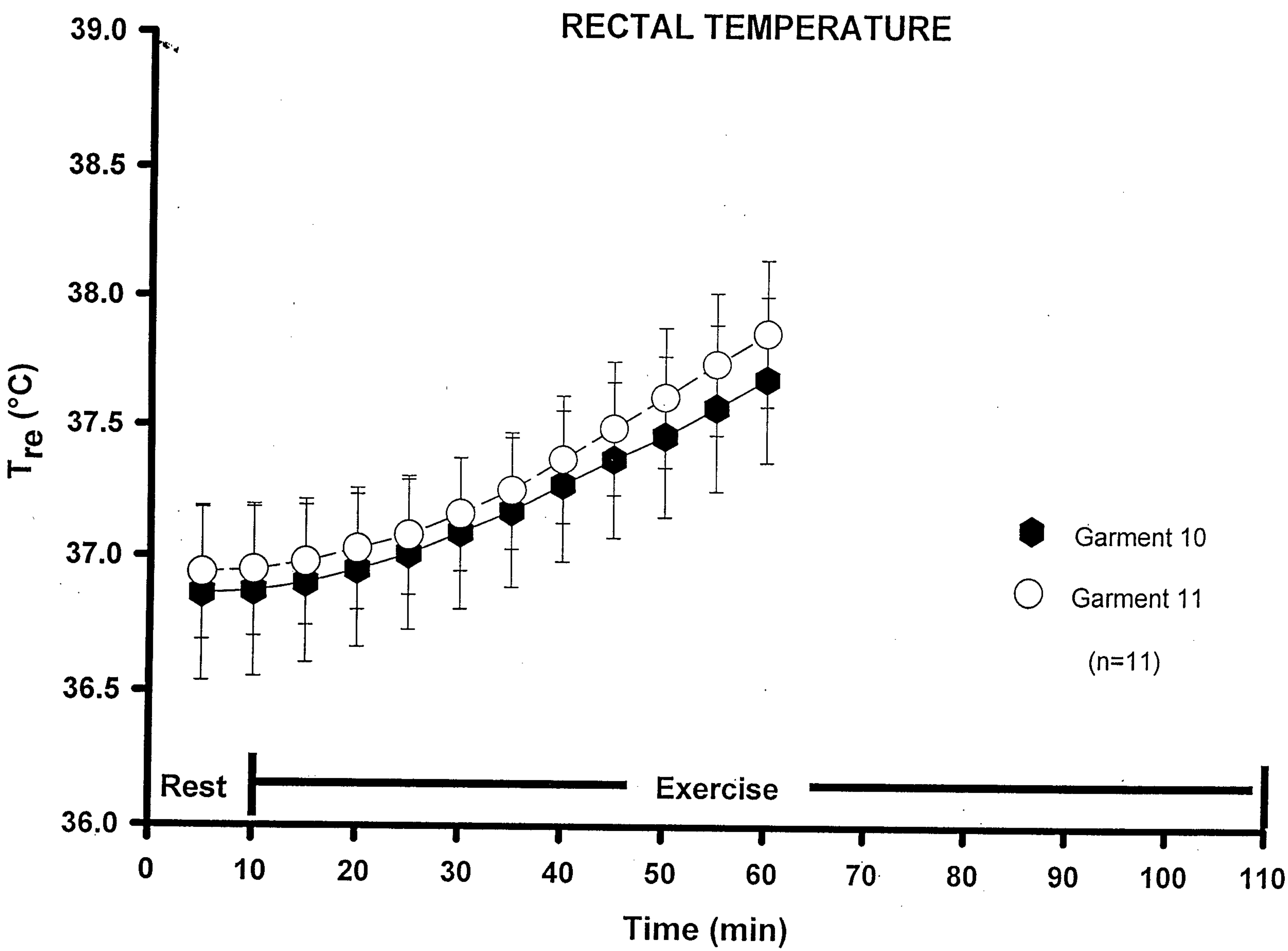
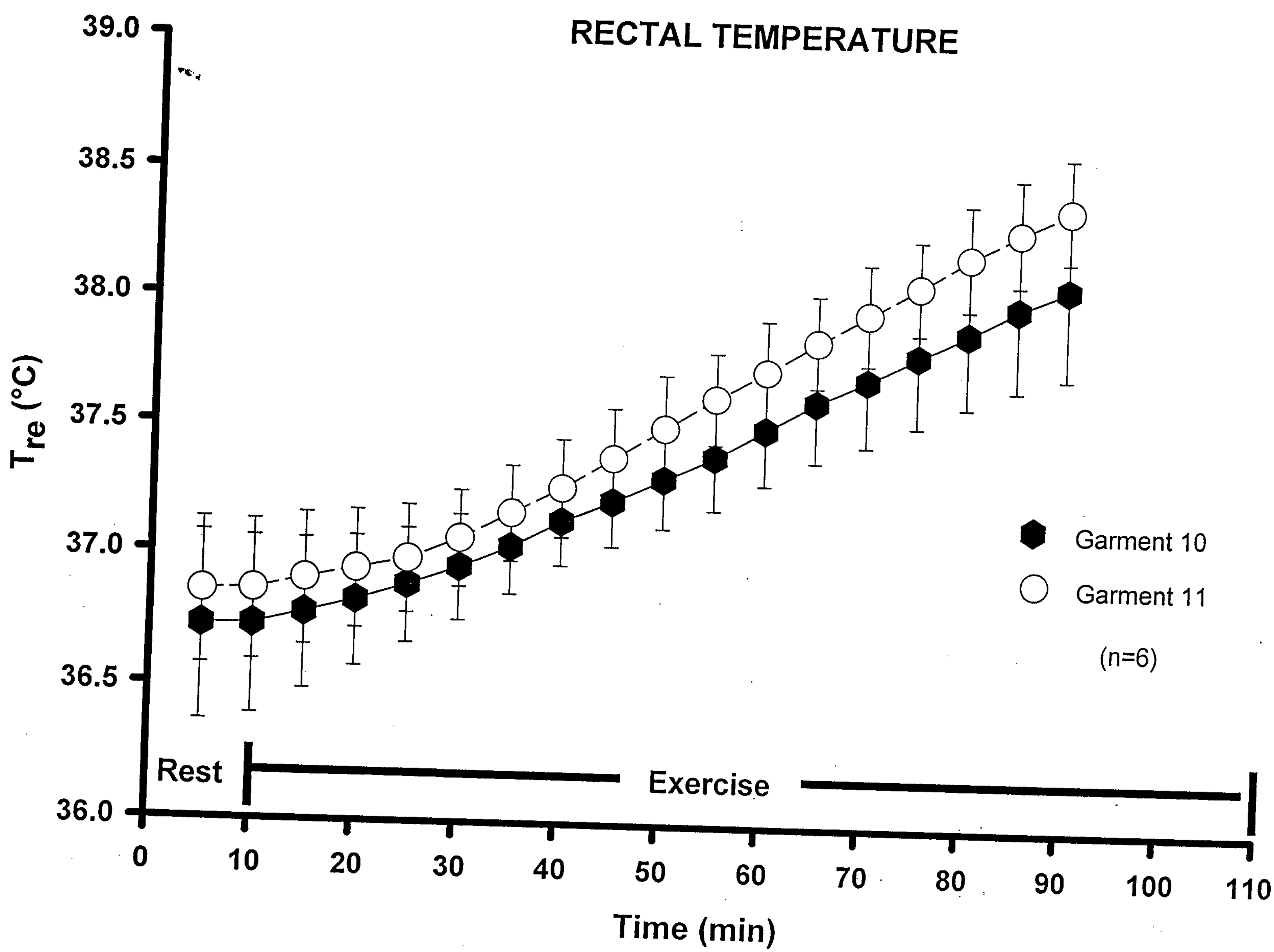

RECTAL TEMPERATURE
Tre (°C)
39.0
38.5
38.0
37.5
37.0
36.5
36.0
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Rest
Exercise
Garment 10
Garment 11
(n=11)

Figure 25b


RECTAL TEMPERATURE
T_{re} (°C)
39.0
38.5
38.0
37.5
37.0
36.5
36.0
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Garment 10
Garment 11
(n=6)

Delta T_{re}: (see Figures 26a-b) In the analysis to 60 min (n=11), after 45 min, from 50 through 60 min, ΔT_{re} was greater during the garment 11 trial. For analyses to 65 min (n=10) and 90 min (n=6), similar differences occur (though not until 75 min in the 90min analysis). In all cases, ΔT_{re} increased over time.

Insert Figures 26a and 26b here

Figure 26a

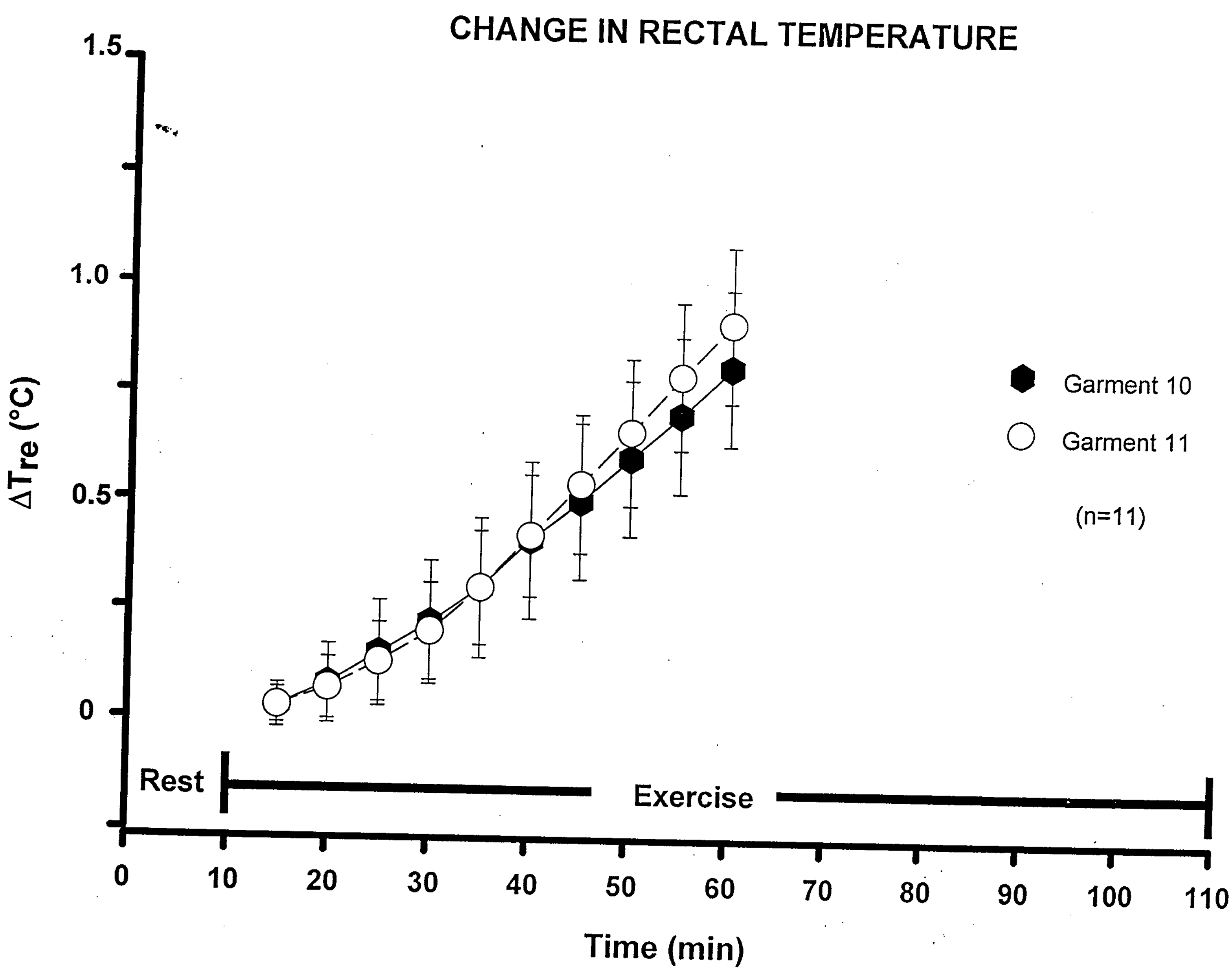
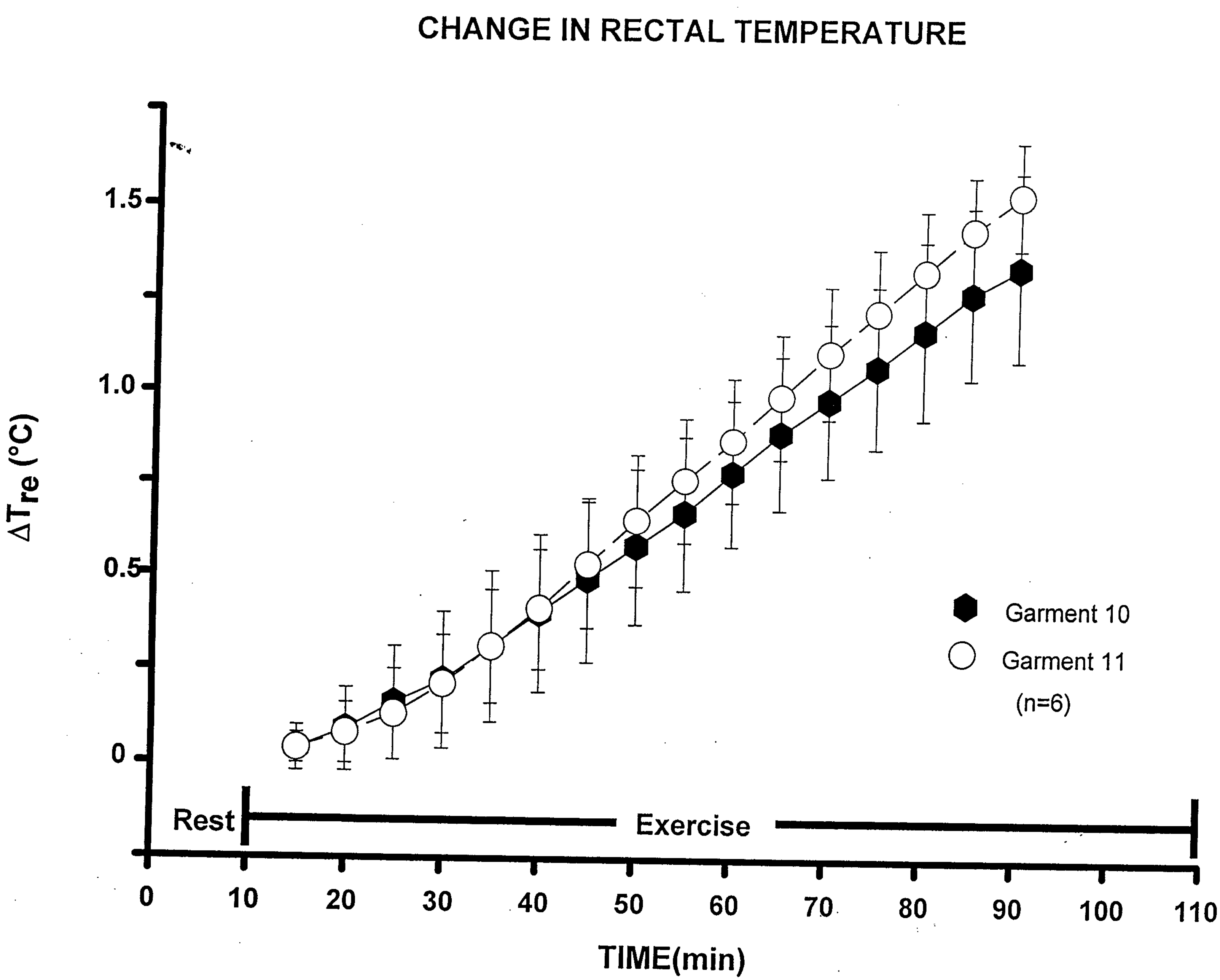

CHANGE IN RECTAL TEMPERATURE
ΔTre (°C)
1.5
1.0
0.5
0
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Garment 10
Garment 11
(n=11)

Figure 26b


CHANGE IN RECTAL TEMPERATURE
ΔTre (°C)
1.5
1.0
0.5
0
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
TIME(min)
Garment 10
Garment 11
(n=6)

$\bar{T}_{sk}$: (see Figures 27a-b) In the 60 min analysis (n=11), $\bar{T}_{sk}$ was not significantly different between garments 10 and 11. $\bar{T}_{sk}$ increased over time in both garments. In the analysis to 90 min (n=6), there were again no significant differences between the garments, and in both, $\bar{T}_{sk}$ increased over time.

Insert Figures 27a and 27b here

Figure 27a

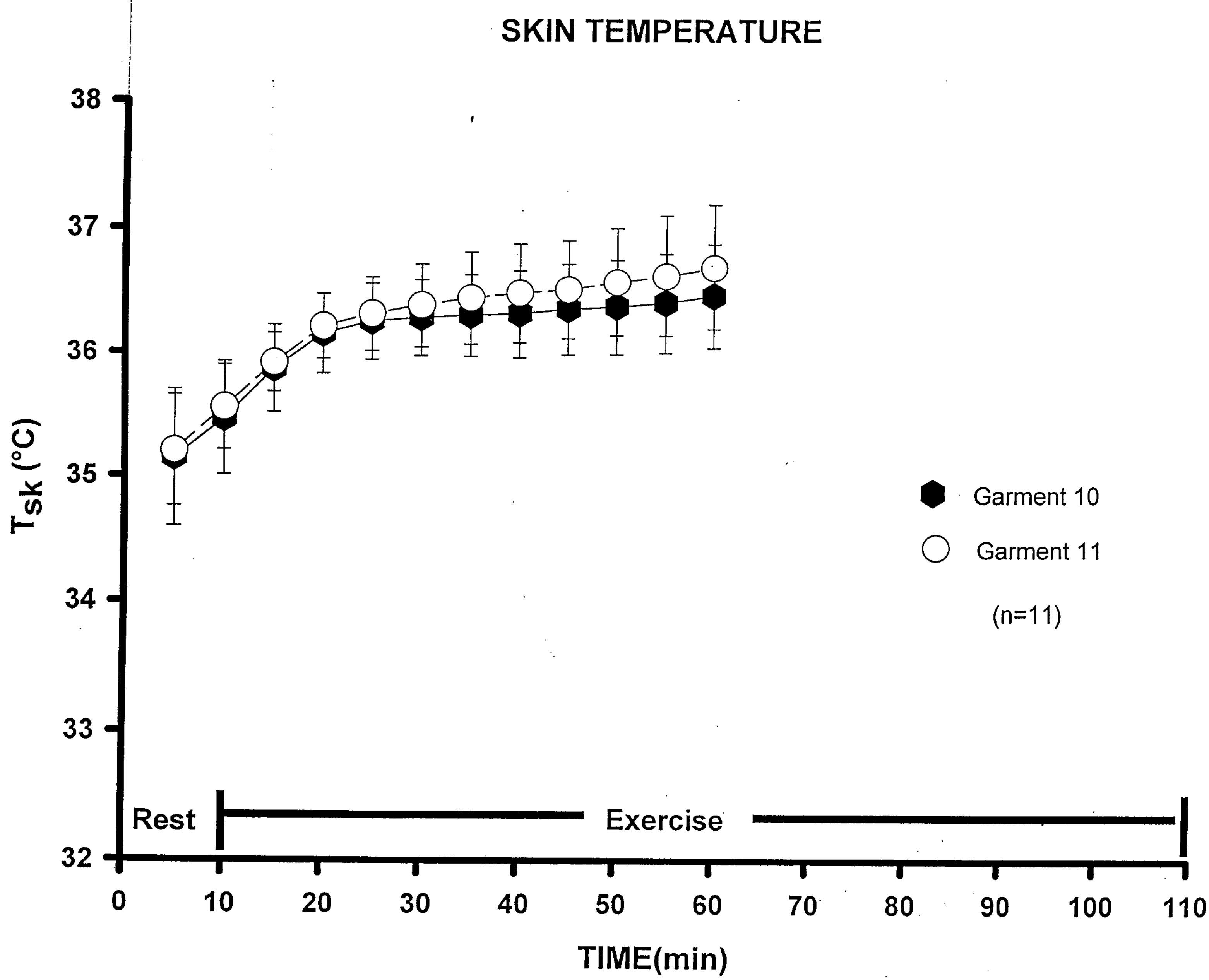
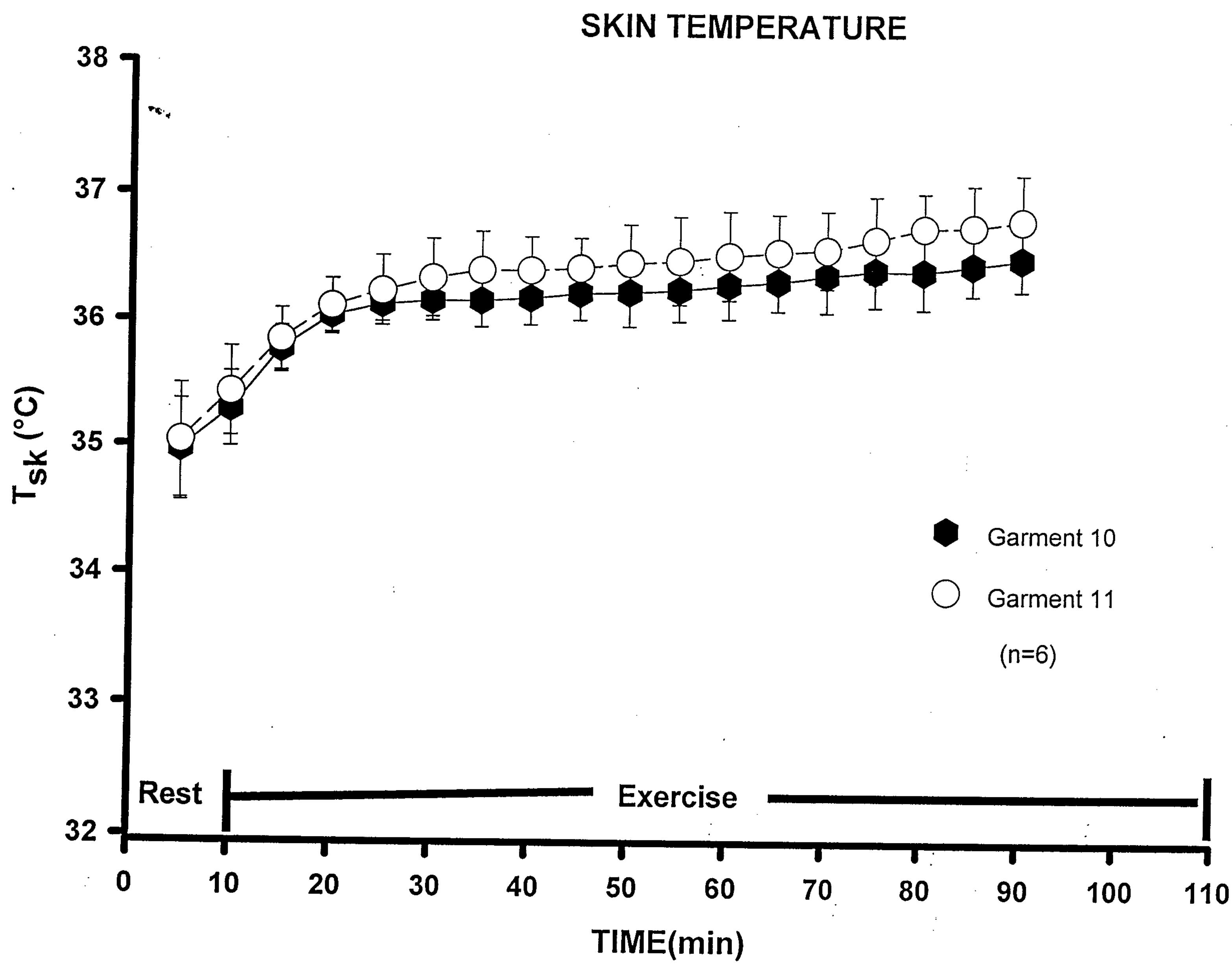

SKIN TEMPERATURE
T_{sk} (°C)
38
37
36
35
34
33
32
Garment 10
Garment 11
(n=11)
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
TIME(min)

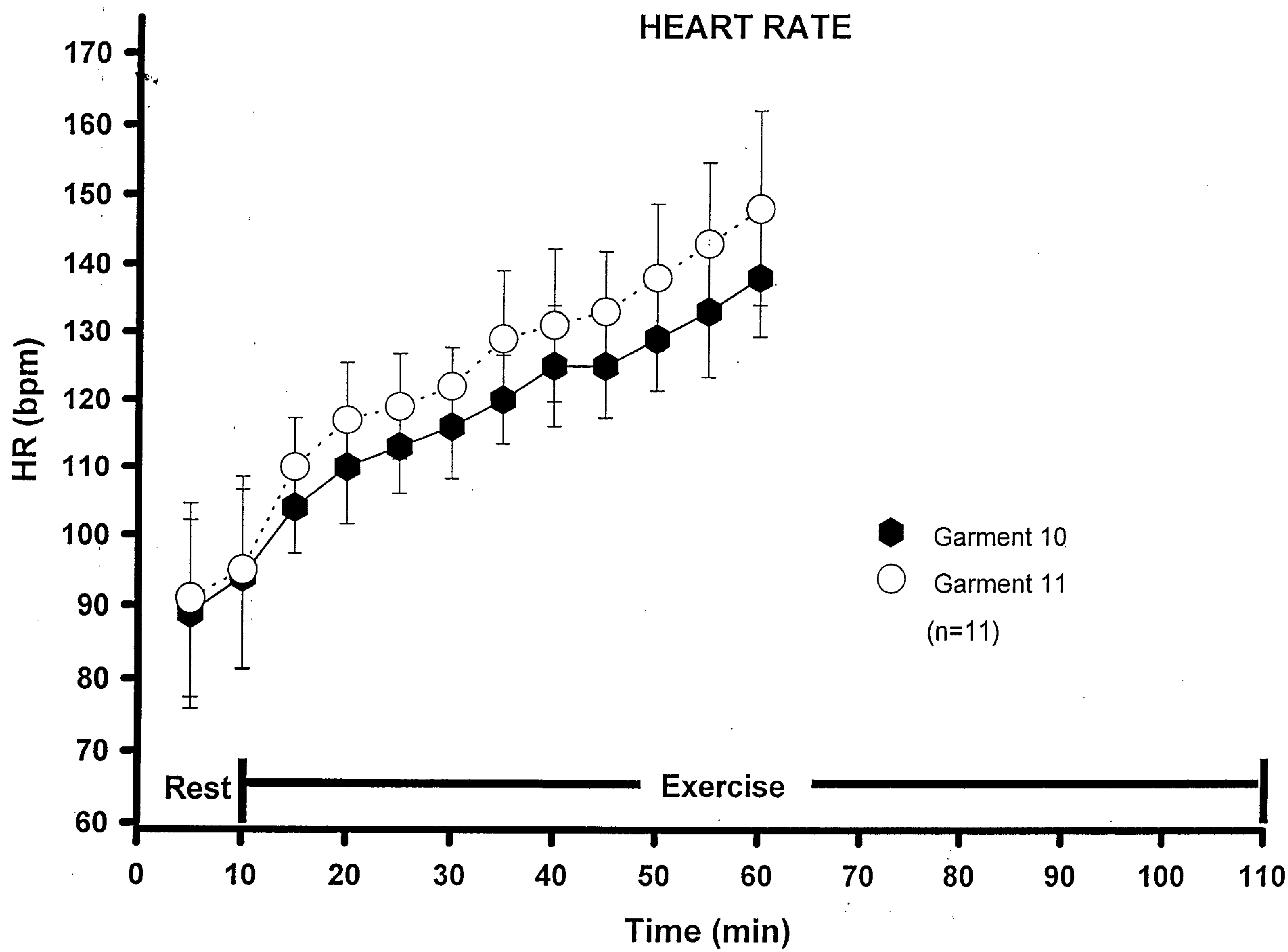
Figure 27b


SKIN TEMPERATURE
T_{sk} (°C)
38
37
36
35
34
33
32
0
10
20
30
40
50
60
70
80
90
100
110
TIME(min)
Rest
Exercise
Garment 10
Garment 11
(n=6)

Heart Rate: (see Figure 28) In the 60 min analysis (n=11), from 50 through 60 min, HR was higher during the garment 11 trial. In both garments, HR increased over time.

Insert Figure 28 here

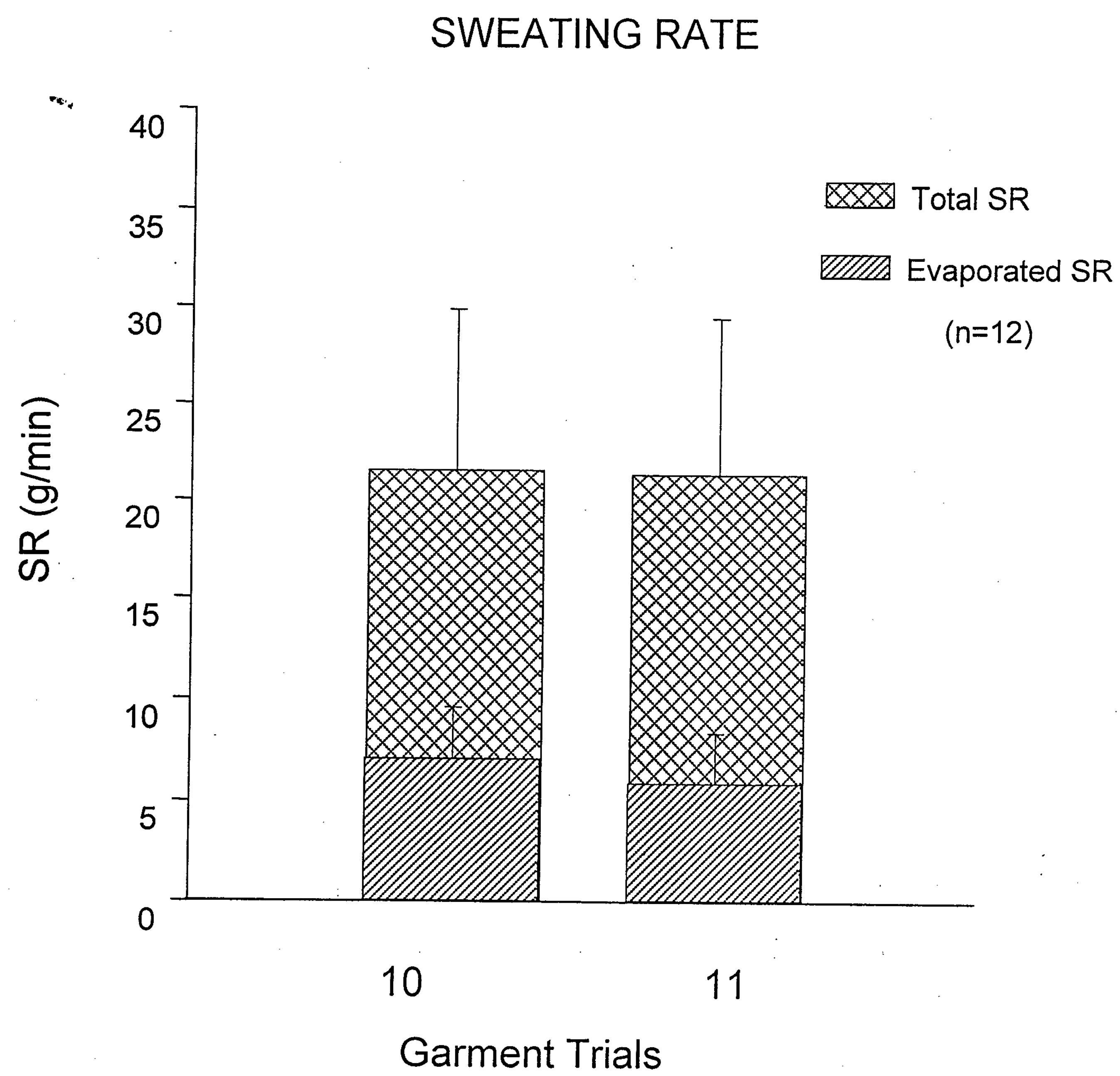
Figure 28


HEART RATE
HR (bpm)
170
160
150
140
130
120
110
100
90
80
70
60
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Garment 10
Garment 11
(n=11)

Sweating Rate and Evaporative Heat Loss: (see Figures 29 and 30) Total SR and the percent evaporated were not different between garments. Evaporative heat loss differences were also not significant.

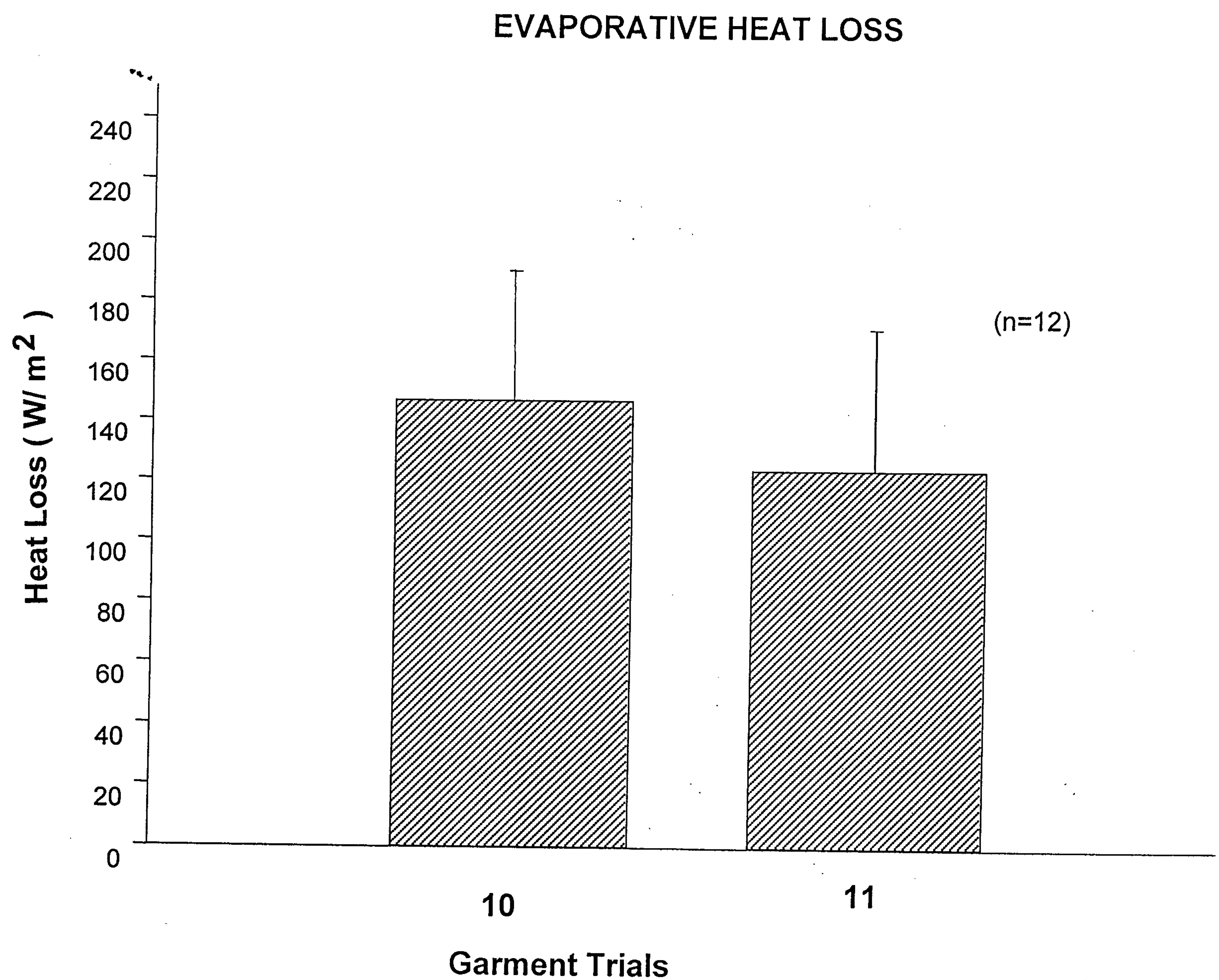
Insert Figures 29 and 30 here

Figure 29



SWEATING RATE
SR (g/min)
0
5
10
15
20
25
30
35
40
Total SR
Evaporated SR
(n=12)
10
11
Garment Trials

Figure 30

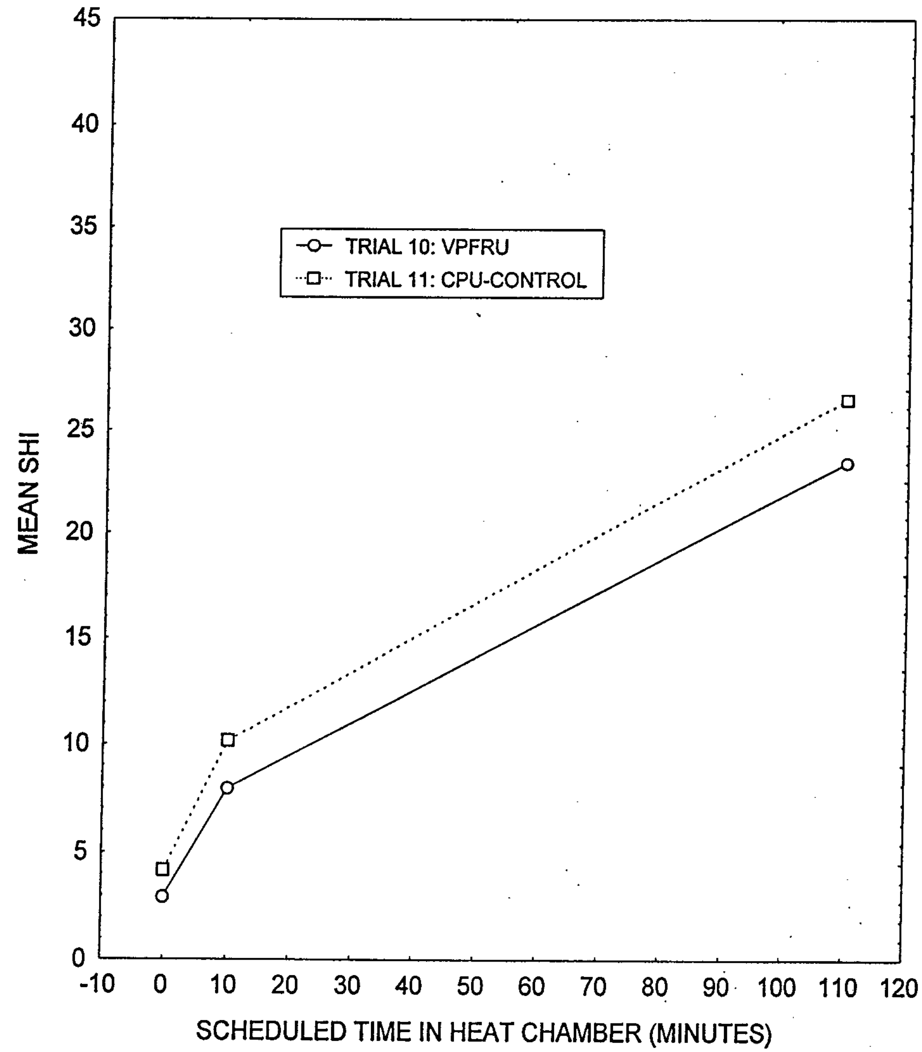

EVAPORATIVE HEAT LOSS
Heat Loss (W/ m2)
0
20
40
60
80
100
120
140
160
180
200
220
240
(n=12)
10
11
Garment Trials

Subjective Data Comparison of Garment Trial 10 (VPFRU) and Garment Trial 11 (CPU-Control) (n=12): There was no significant difference in SHI scores between Garment Trial 10 (11.42 $\pm$ 13.82 s.d.) and Garment Trial 11 (13.61 $\pm$ 14.32 s.d.). However, for both garment trials, SHI scores were significantly higher ($F(2,22)=19.63$; $p < 0.01$) during the 100-minute-walk in 95° heat (24.96 $\pm$ 16.42 s.d.) as compared to SHI scores prior to entering the test chamber (3.54 $\pm$ 4.72 s.d.) or during the 10-minute-prewalk (9.04 $\pm$ 7.52 s.d.). There was no significant garment x administration interaction. See Figure 31.

Insert Figure 31 here

Figure 31

Plot of SHI Means by Scheduled Time in Chamber
2-way interaction (non-significant)
Time in Chamber by Garment



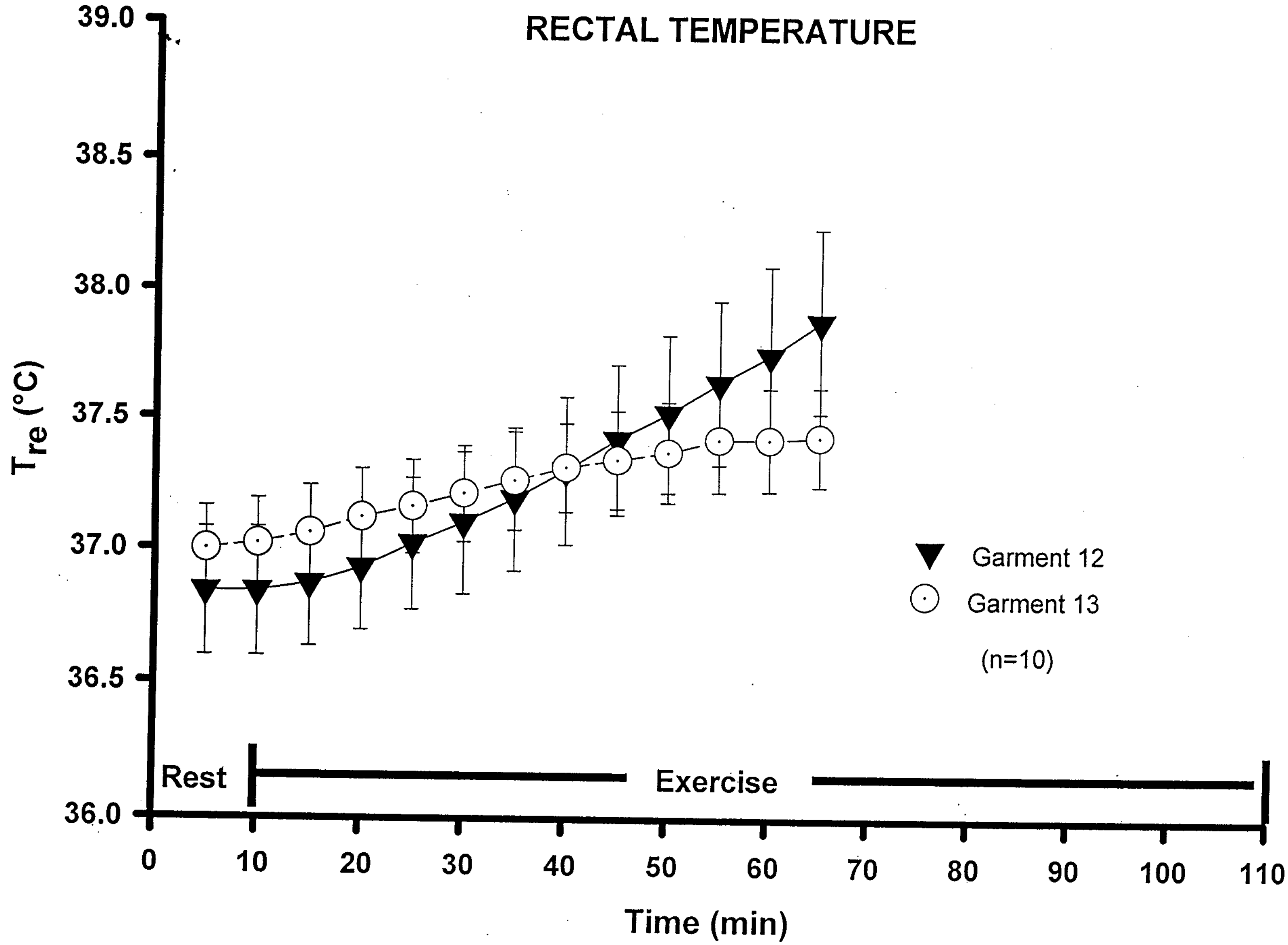
Garment Trials 12 and 13

Test Time: (see Figure 16) Test time for the garment 12 trial (n=10, 88 min) was significantly less than that for trial 13 (103 min).

T_{re}: (see Figure 32) In the analysis to 65 min (n=10), from min 50 through min 65, T_{re} was higher for trial 12. We would expect differences to show up sooner, but T_{re} was higher in trial 13 from min 0 through min 25. Since these trials were not counterbalanced (due to garment availability and test environment), there may be a reason unrelated to testing for the higher T_{re} at the start of the garment 13 trials. (These trials occured on two different test days for each garment.) When T_{re} was analyzed to 75 min (n=8), it continued to rise faster and to be significantly higher from min 50 through min 75, in trial 12 compared to 13. In both garments, T_{re} increased over time, but did so faster in trial 12.

Insert Figure 32 here

Figure 32



RECTAL TEMPERATURE
T_{re} (°C)
39.0
38.5
38.0
37.5
37.0
36.5
36.0
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Rest
Exercise
Garment 12
Garment 13
(n=10)

Delta T_{re}: (see Figures 33a-b) In the 65 min analysis, ΔT_{re} was greater in trial 12 than 13, from 35 through 65 min. In the 75 min analysis, ΔT_{re} was greater in trial 12 from 40 through 75 min, and was increasing faster than ΔT_{re} in trial 13.

Insert Figures 33a and 33b here

Figure 33a

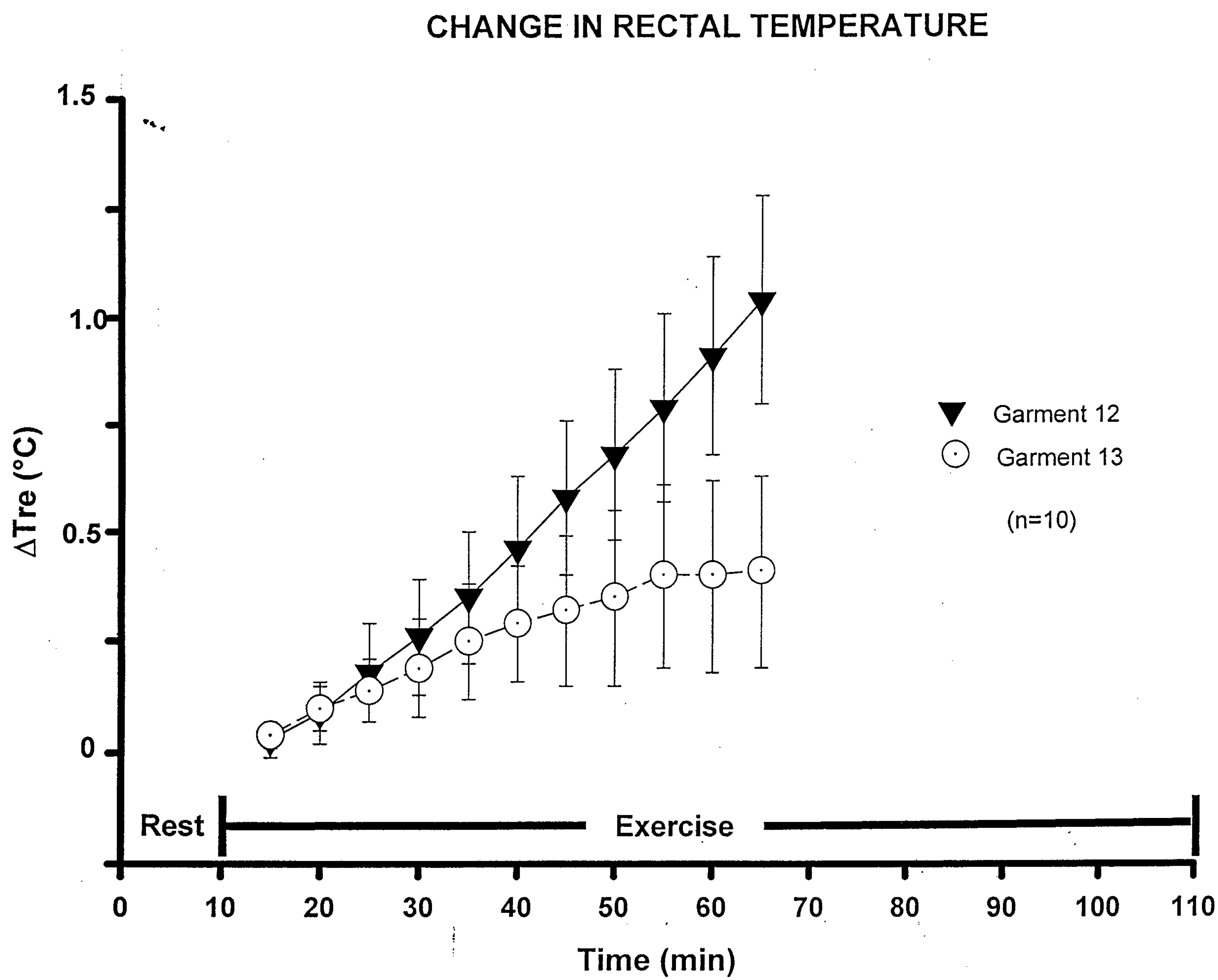
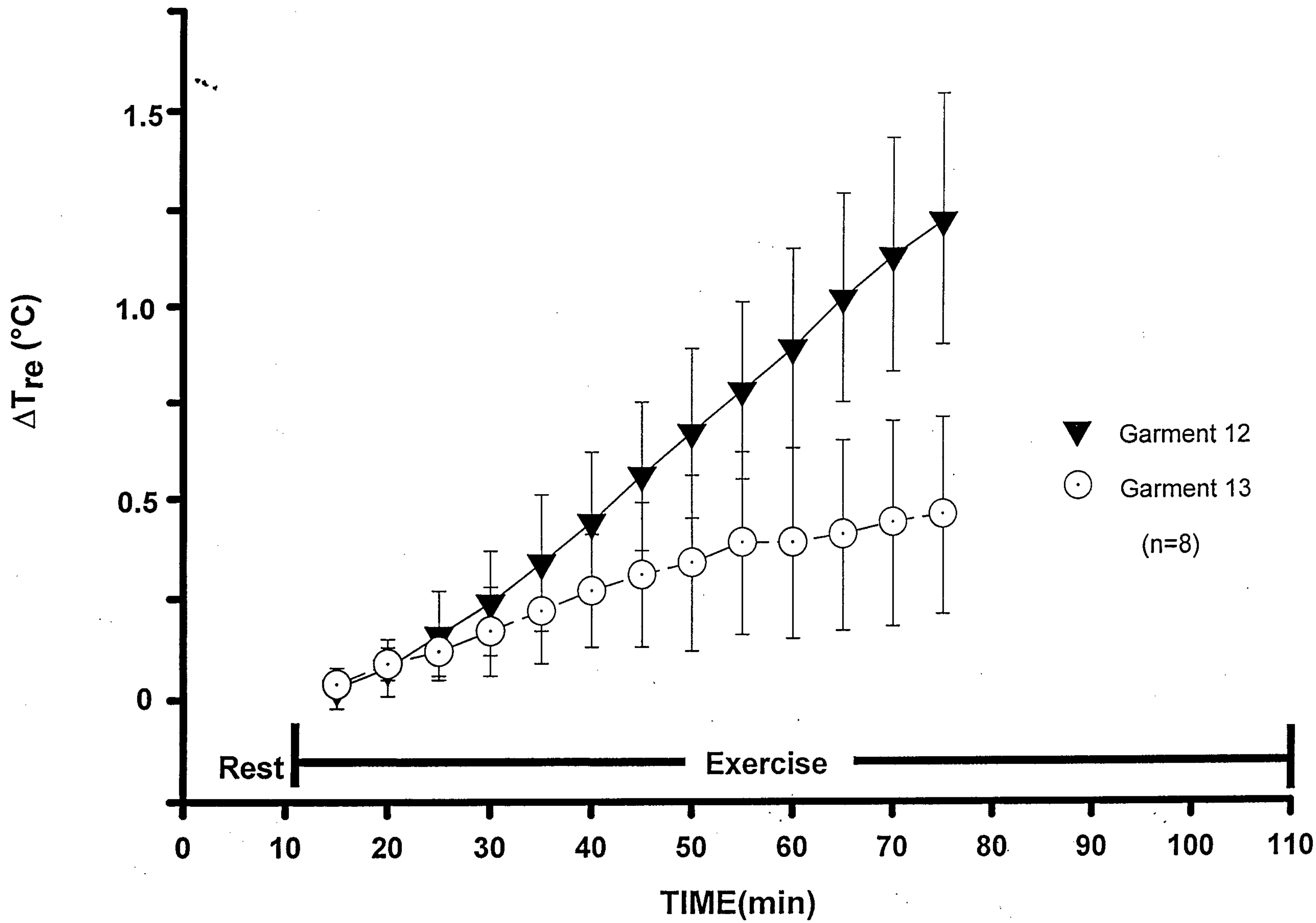

CHANGE IN RECTAL TEMPERATURE
ΔTre (°C)
1.5
1.0
0.5
0
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Garment 12
Garment 13
(n=10)

Figure 33b

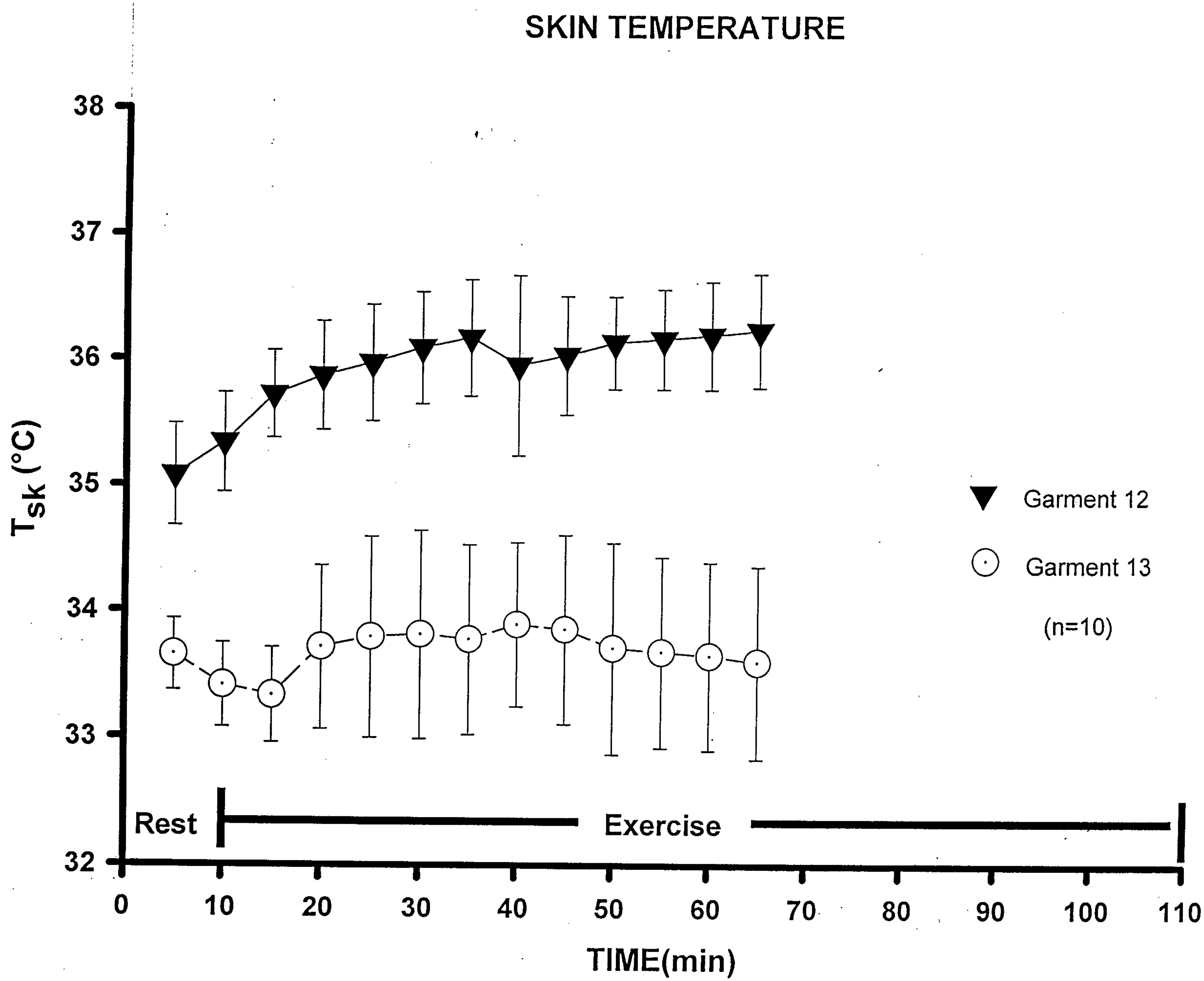
CHANGE IN RECTAL TEMPERATURE



$\bar{T}_{sk}$: (see Figure 34) As soon as subjects entered the environmental chamber, $\bar{T}_{sk}$ was higher during trial 12, and remained higher throughout testing. In trial 12, $\bar{T}_{sk}$ increased slowly over time. In trial 13, $\bar{T}_{sk}$ decreased after subjects entered the chamber, and then increased only slightly during testing.

Insert Figure 34 here

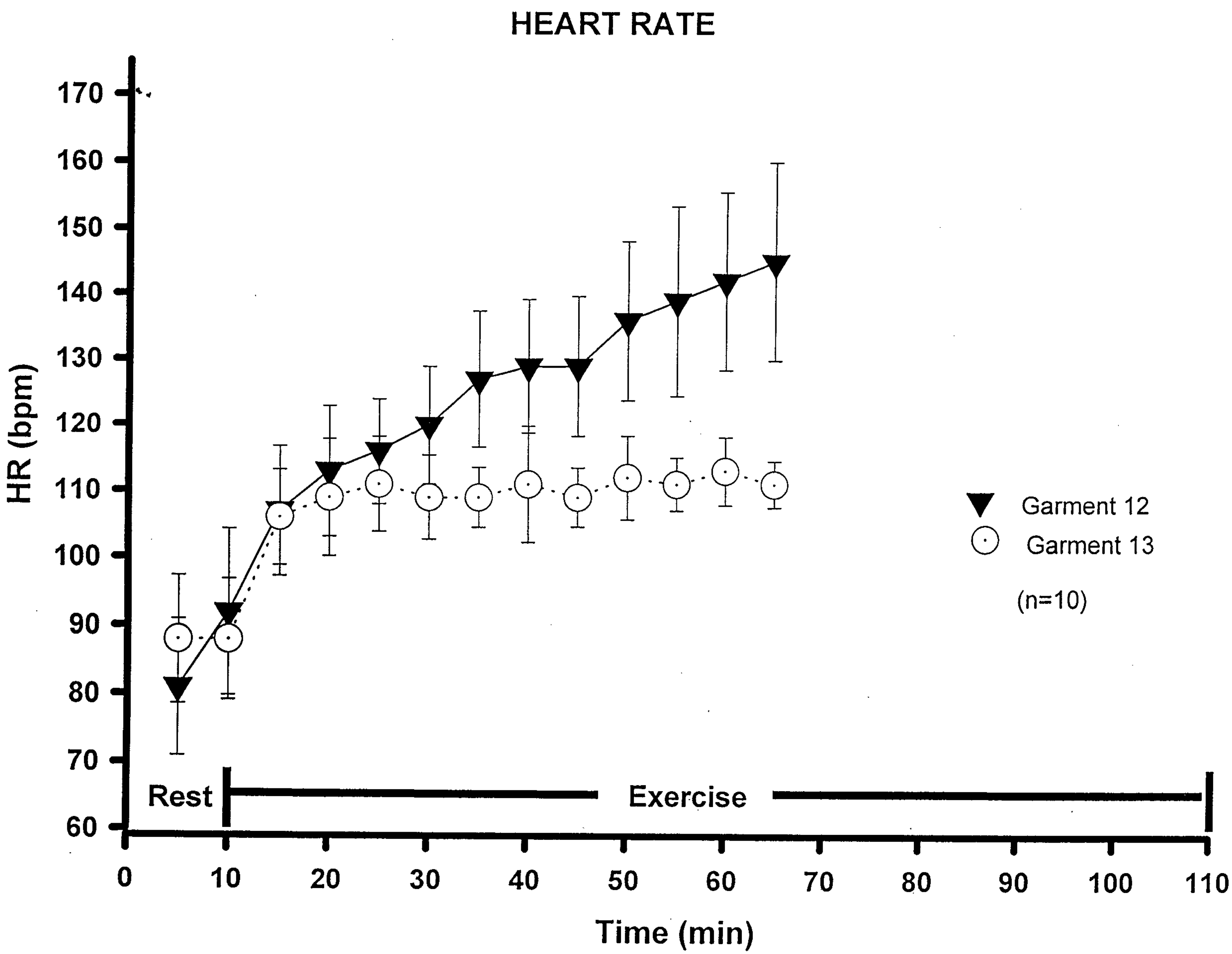
Figure 34


SKIN TEMPERATURE
T_{sk} (°C)
38
37
36
35
34
33
32
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
TIME(min)
Garment 12
Garment 13
(n=10)

Heart Rate: (see Figures 35a-b) For the 65 min analysis (n=10), HR was signficantly higher during trial 12 from min 30 through min 65. In trail 12, HR increased consistently throughout testing, while for trial 13, HR increased only with the start of exercise. Similar differences were seen when the analysis was extended to 75 min (n=8).

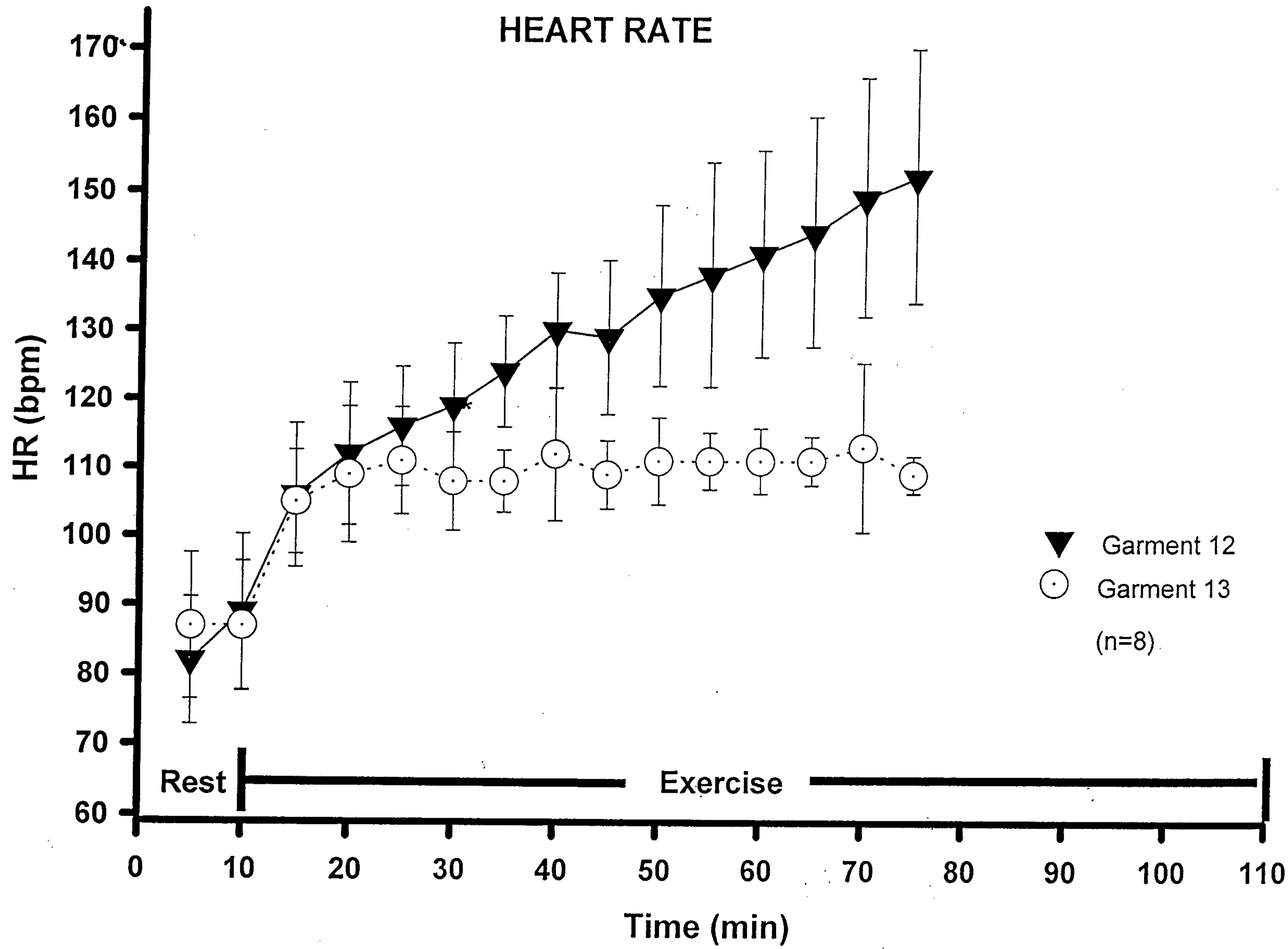
Insert Figures 35a and 35b here

Figure 35a



HEART RATE
HR (bpm)
170
160
150
140
130
120
110
100
90
80
70
60
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Rest
Exercise
Garment 12
Garment 13
(n=10)

Figure 35b


HEART RATE
HR (bpm)
170
160
150
140
130
120
110
100
90
80
70
60
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Rest
Exercise
Garment 12
Garment 13
(n=8)

Sweating Rate and Evaporative Heat Loss: (see Figures 21 and 22) Total SR was greater during trial 12, but the % evaporated was greater for trial 13.

Subjective Data Comparison of Garment Trial 12 (worst-case JSLIST-D-NFR2 at 95°) and Garment Trial 13 (worst-case JSLIST-D-NFR2 at 75°) (n=10): There was a significant difference ($F(1,9)=30.42$; $p < 0.01$) in the SHI mean scores between Garment Trial 12 (13.83 ± 14.24 s.d.) and Garment Trial 13 (4.17 ± 4.05 s.d.). SHI scores were significantly higher in the 95° condition than in the 75° condition. The SHI mean score was higher ($F(2,18)=21.13$; $p < 0.01$) during the 100-minute-walk (16.80 ± 16.41 s.d.) as compared to SHI scores prior to entering the test chamber (4.00 ± 2.96 s.d.) or during the 10-minute-prewalk (6.20 ± 5.63 s.d.). A significant garment x administration interaction ($F(2,18)=15.18$; $p < 0.01$) showed that this administration effect was limited to Garment Trial 12 (see Figure 36). During the 100-minute-walk in the 95° condition, the SHI score was significantly higher (27.50 ± 17.16 s.d.) as compared to prior to entering the test chamber (5.10 ± 2.64 s.d.) or during the 10-minute-prewalk (8.90 ± 5.72 s.d.). During the 100-minute-walk in the 75° condition, the SHI score was not significantly higher (6.10 ± 4.46 s.d.) as compared to prior to entering the test chamber (2.90 ± 2.96 s.d.) or during the 10-minute-prewalk (3.50 ± 4.22 s.d.). SHI scores were also significantly higher during the 100-minute-walk at 95° as compared to the 100-minute-walk at 75° .

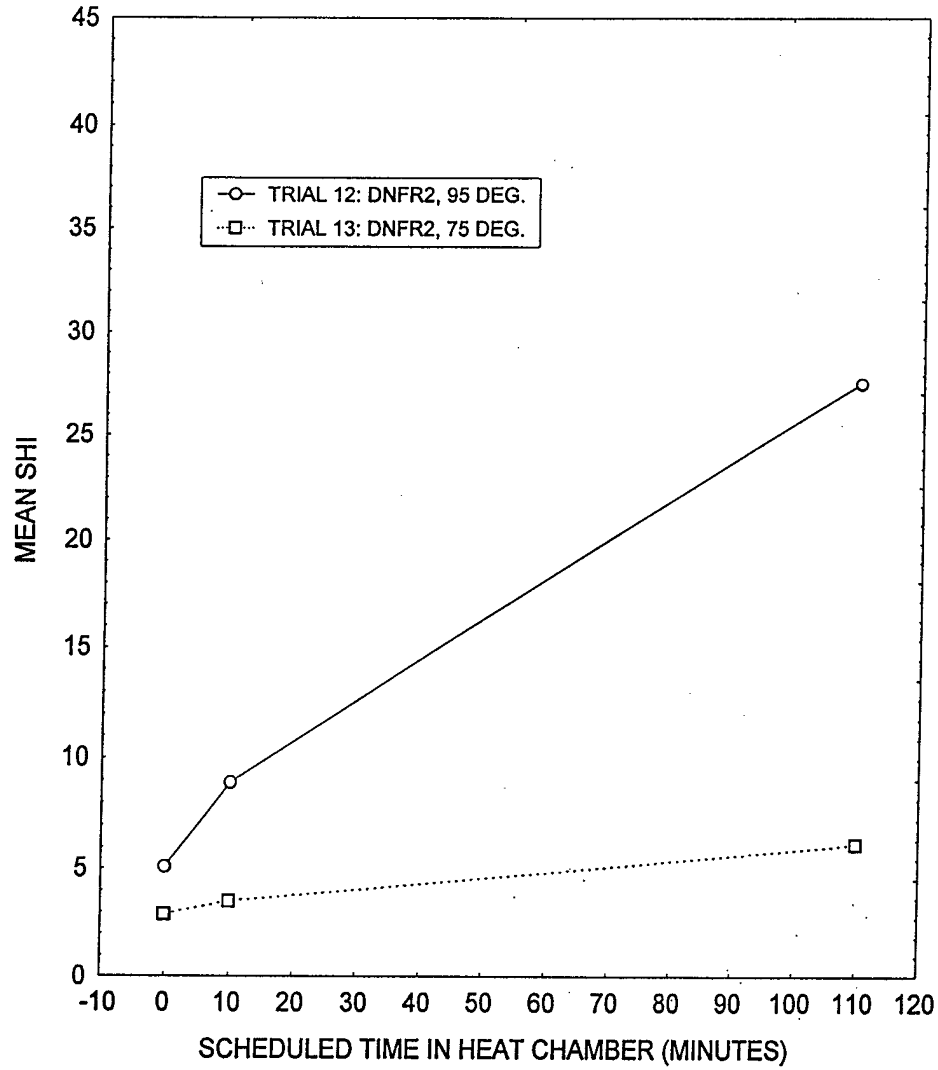
Insert Figure 36 here

Figure 36

Plot of SHI Means by Scheduled Time in Chamber

2-way interaction

$F(2,18)=15.18$; $p<.01$



Garment Trials 13 and 14

Test Time: (see Figure 16) Test time was not significantly different between garment trials 13 (102 min) and 14 (89 min).

T_{re}: (see Figures 37a-b) In the analysis to 55 min (n=11), there were no significant differences between garments. In each garment, T_{re} increased significantly over time by 55 min only compared to pre-exercise values. The analysis to 75 min (n=9) was similar, there were no significant differences between garments.

Insert Figures 37a and 37b here

Figure 37a

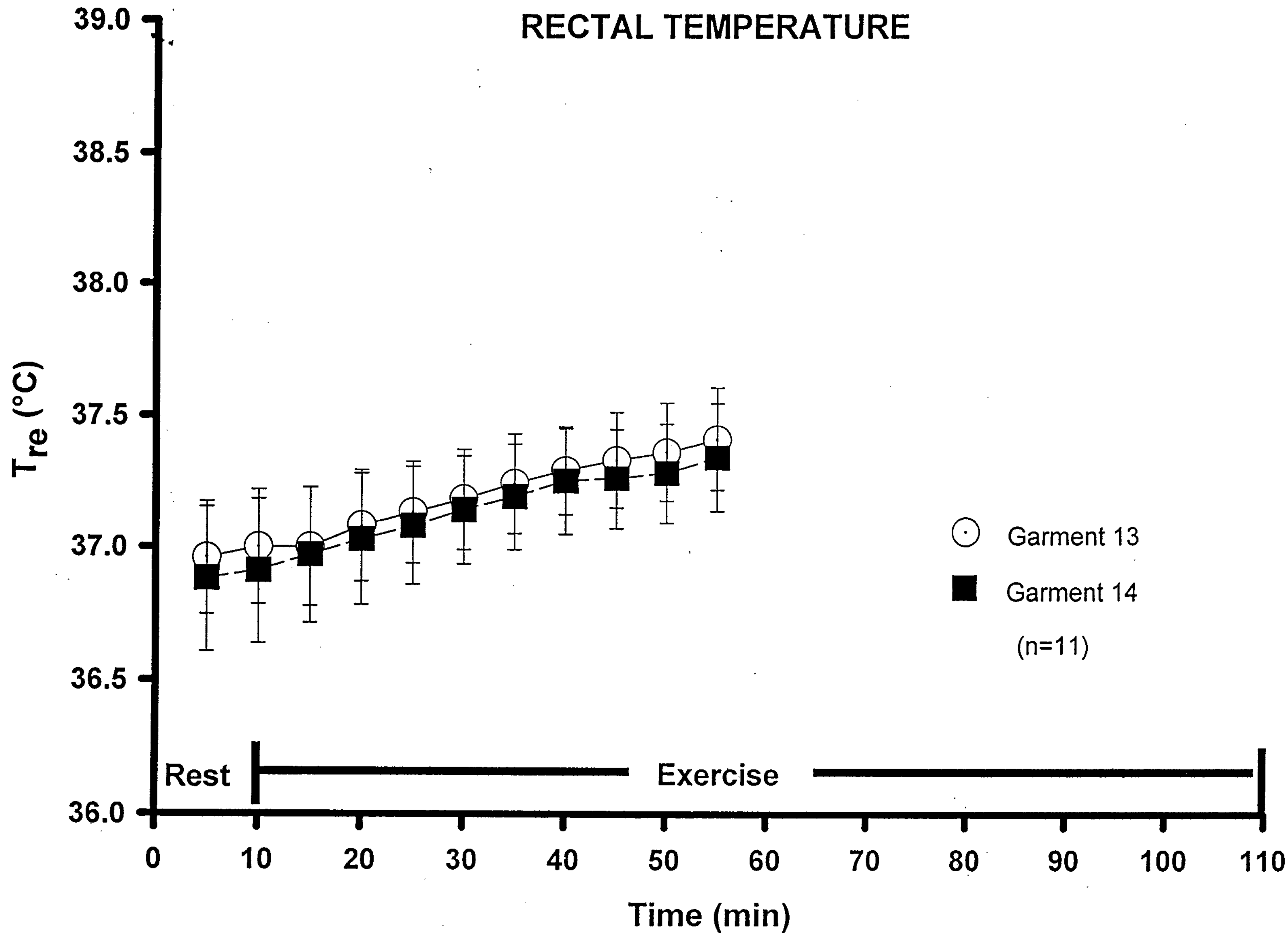
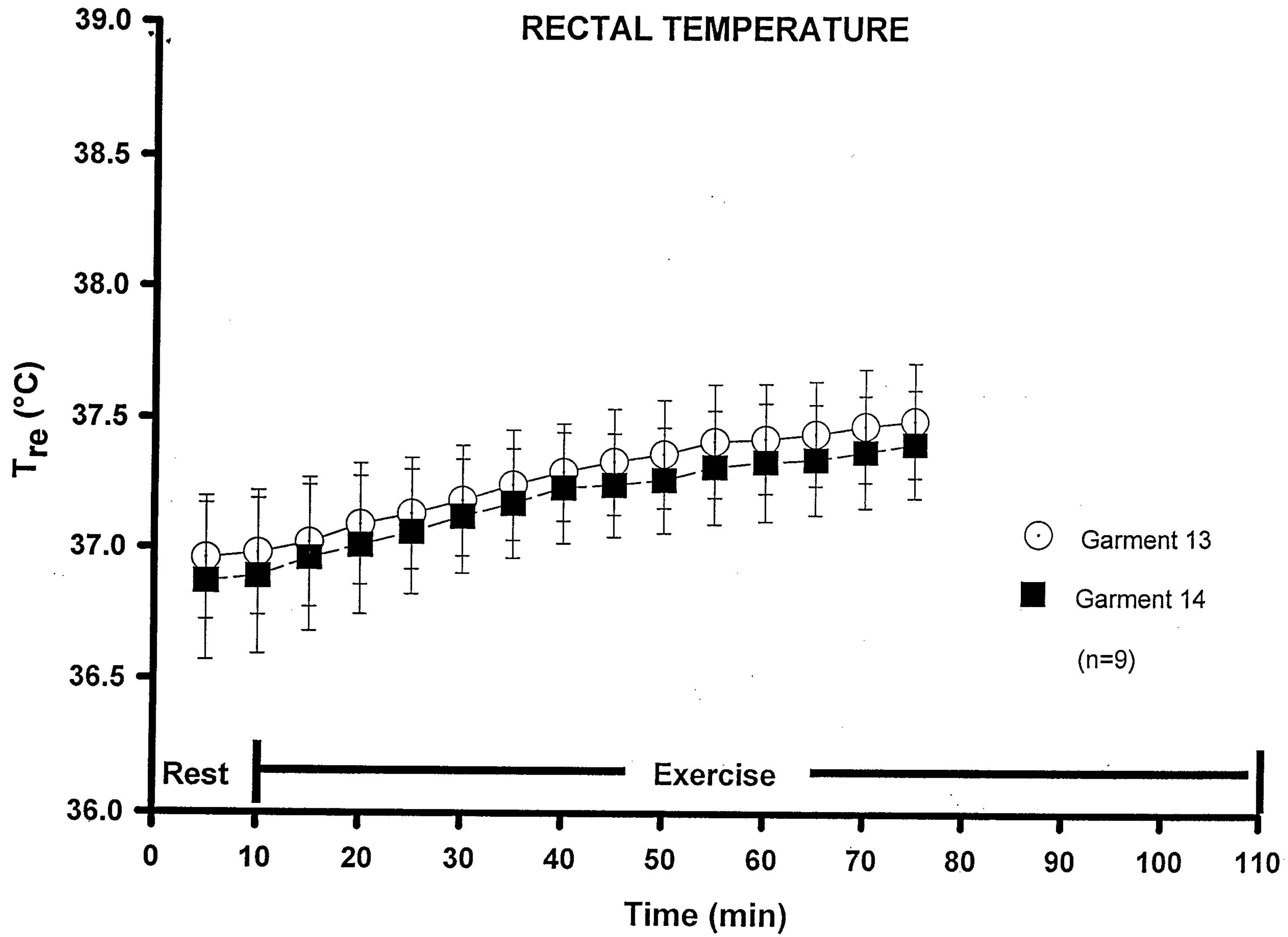

RECTAL TEMPERATURE
T_{re} (°C)
39.0
38.5
38.0
37.5
37.0
36.5
36.0
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Garment 13
Garment 14
(n=11)

Figure 37b



RECTAL TEMPERATURE
T_{re} (°C)
39.0
38.5
38.0
37.5
37.0
36.5
36.0
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Garment 13
Garment 14
(n=9)

Delta T_{re}: (see Figures 38a-b) The 55 min (n=11) and 75 min (n=9)analyses showed results similar to those for T_{re}. There were no significant differences between garments.

Insert Figures 38a and 38b here

Figure 38a

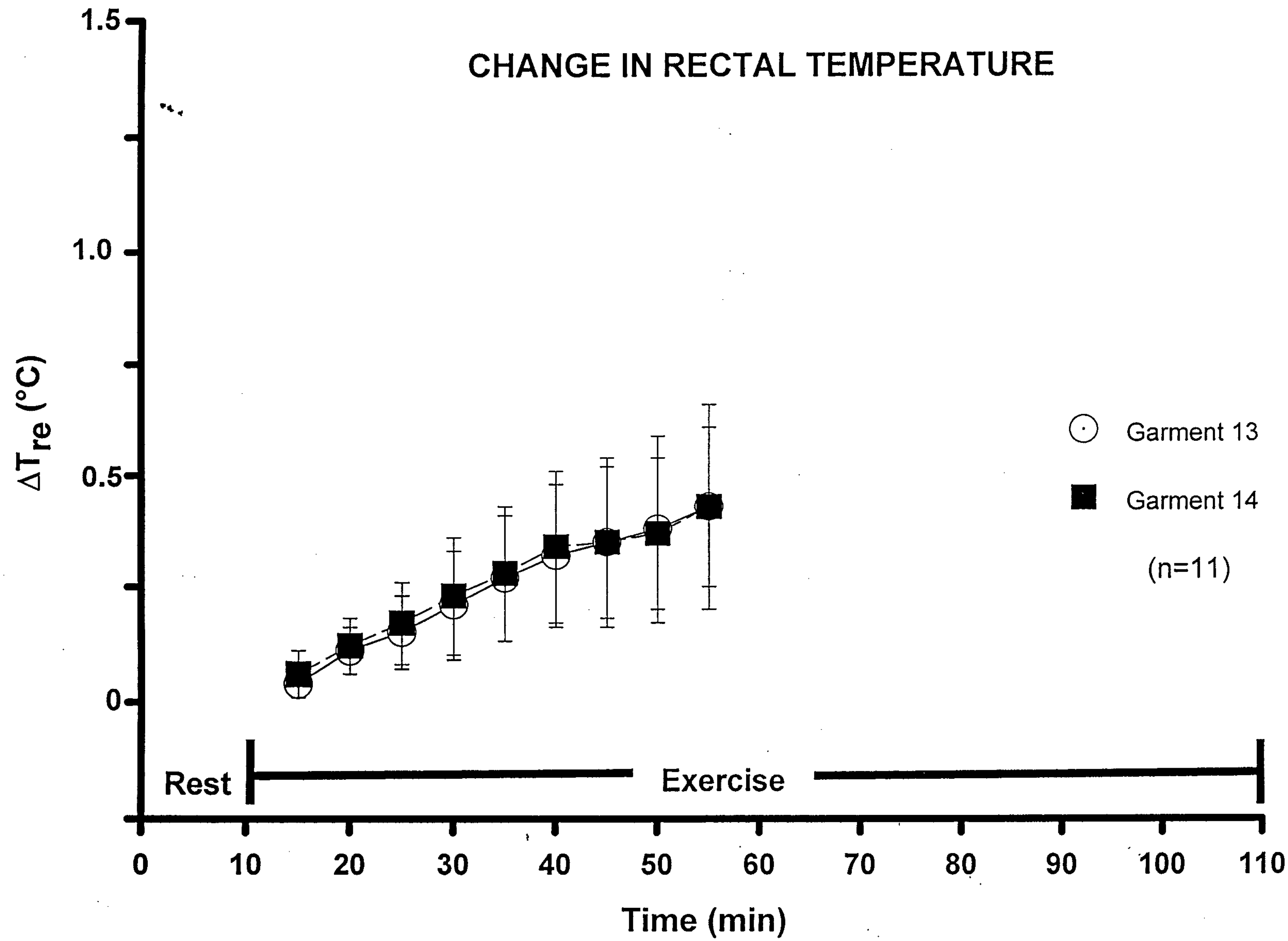
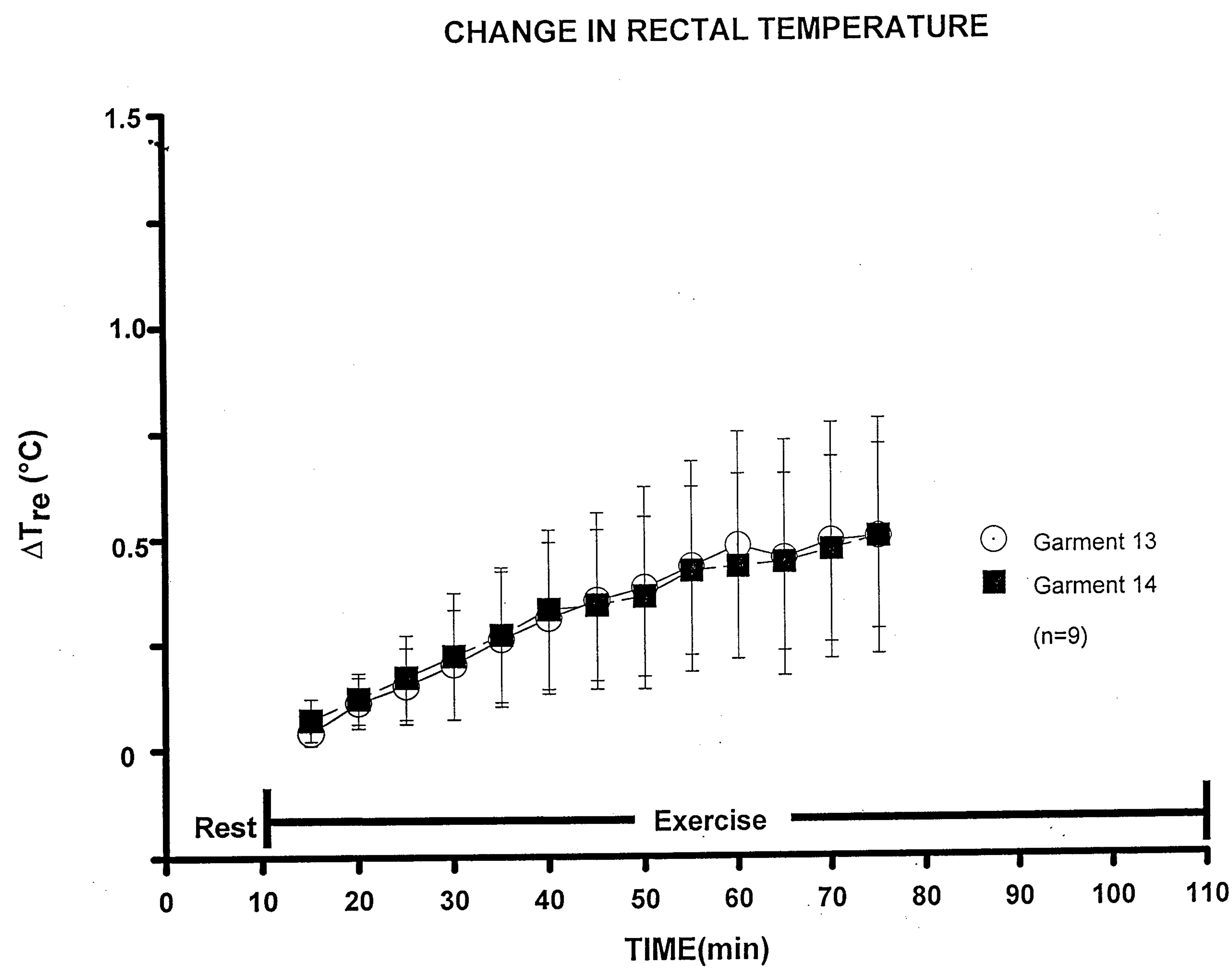

CHANGE IN RECTAL TEMPERATURE
ΔTre (°C)
1.5
1.0
0.5
0
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Garment 13
Garment 14
(n=11)

Figure 38b

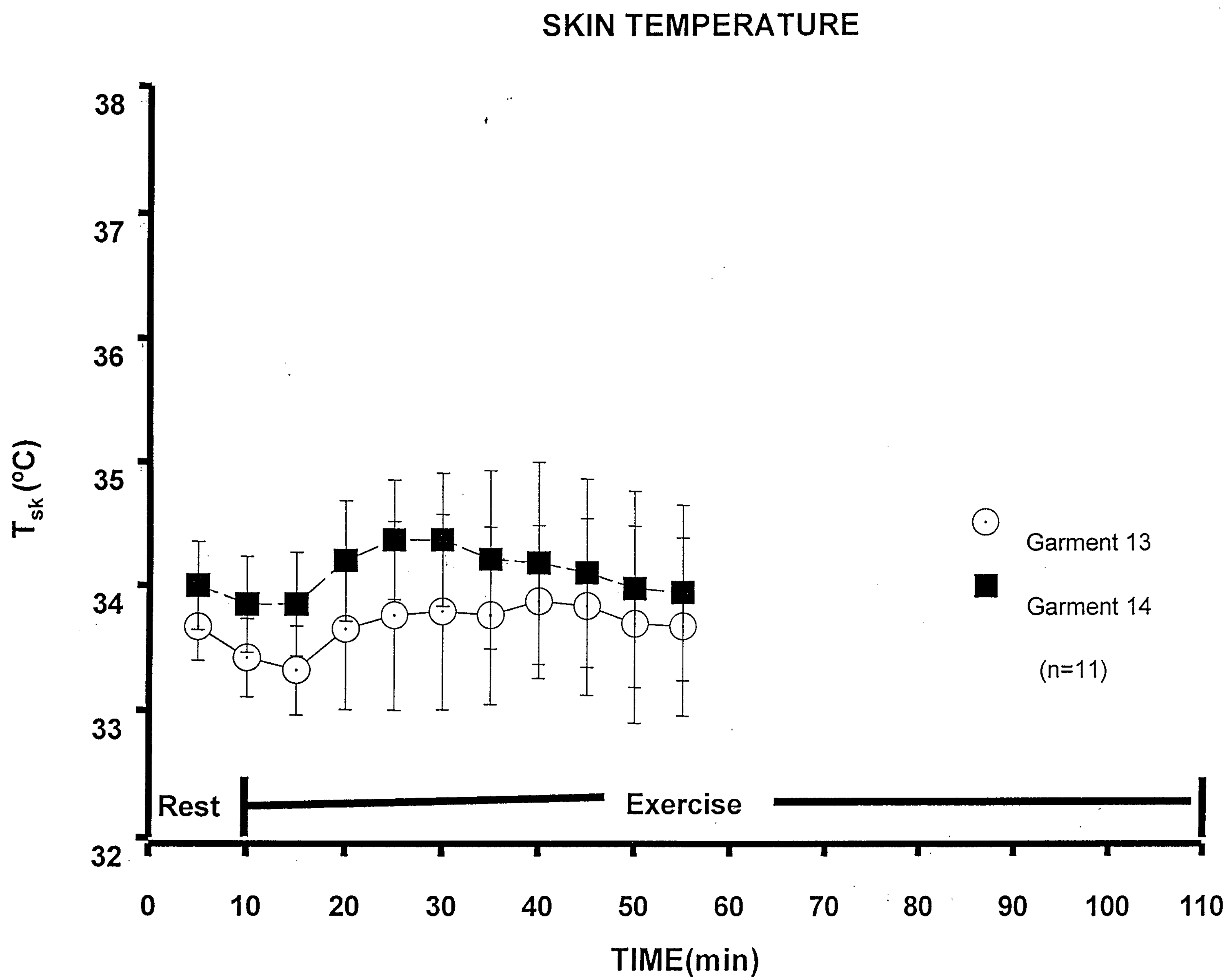


CHANGE IN RECTAL TEMPERATURE
ΔTre (°C)
1.5
1.0
0.5
0
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
TIME(min)
Garment 13
Garment 14
(n=9)

$\bar{T}_{sk}$: (see Figure 39) In the 55 min analysis (n=11), differences in $\bar{T}_{sk}$ between garments were significant from min 15 through min 35 (14>13). Some changes occurred over time but values were relatively unchanged.

Insert Figure 39 here

Figure 39


SKIN TEMPERATURE
T_{sk} (°C)
38
37
36
35
34
33
32
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
TIME(min)
Garment 13
Garment 14
(n=11)

Heart Rate: (see Figures 40a-b) In the analysis to 55 min, HR between garments was not different. In both trials HR increased at the start of exercise, and was relatively stable thereafter. In the analysis to 75 min (n=8), HR between garments was not different. In trial 13, the only increase in HR over time was at the onset of exercise. For trial 14, HR increased at the onset of exercise, and by 70 and 75 min was higher than at 15 min, which was higher than pre-exercise.

Insert Figures 40a and 40b here

Figure 40a

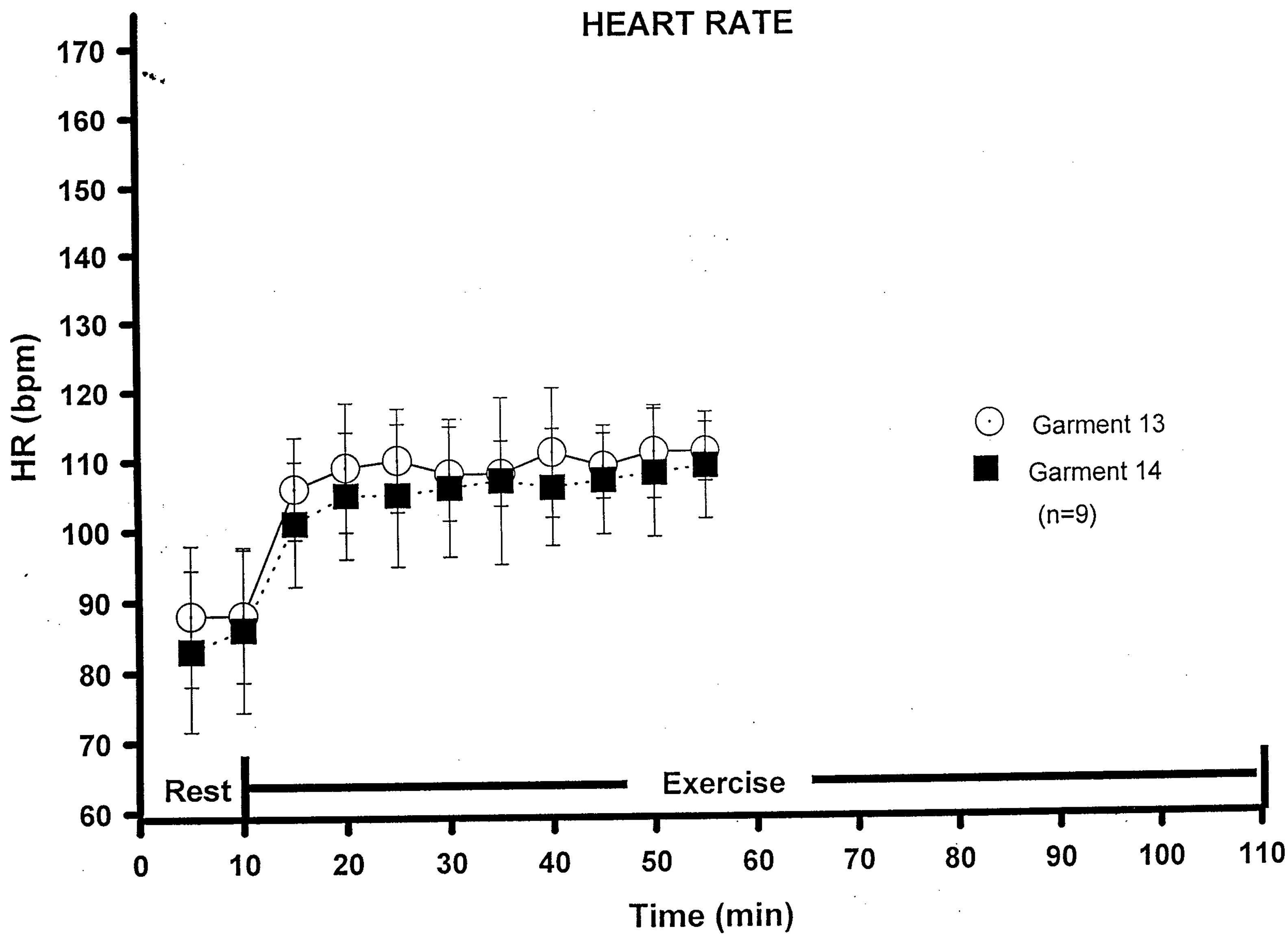
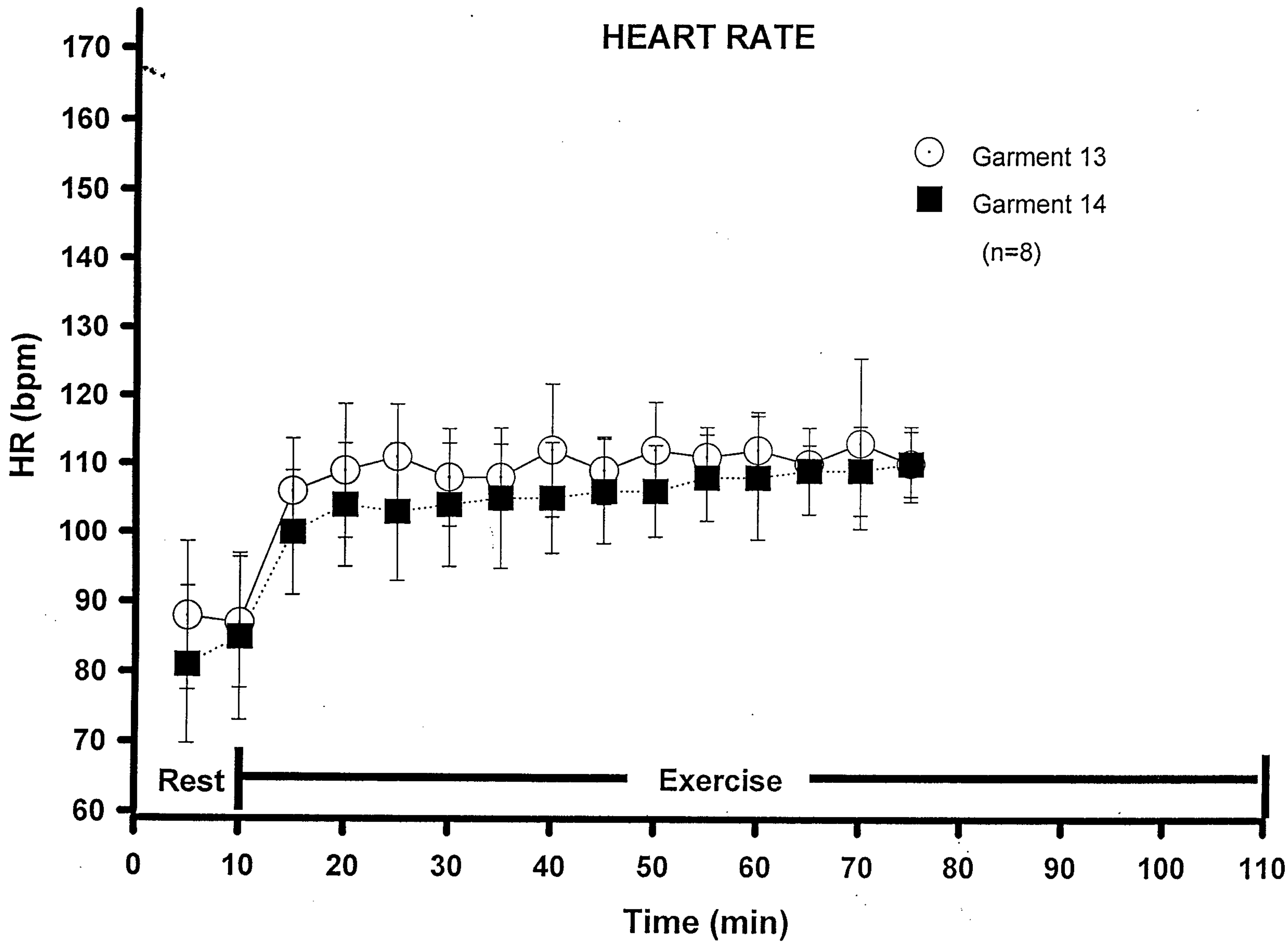

HEART RATE
HR (bpm)
170
160
150
140
130
120
110
100
90
80
70
60
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)
Garment 13
Garment 14
(n=9)

Figure 40b


HEART RATE
Garment 13
Garment 14
(n=8)
HR (bpm)
170
160
150
140
130
120
110
100
90
80
70
60
Rest
Exercise
0
10
20
30
40
50
60
70
80
90
100
110
Time (min)

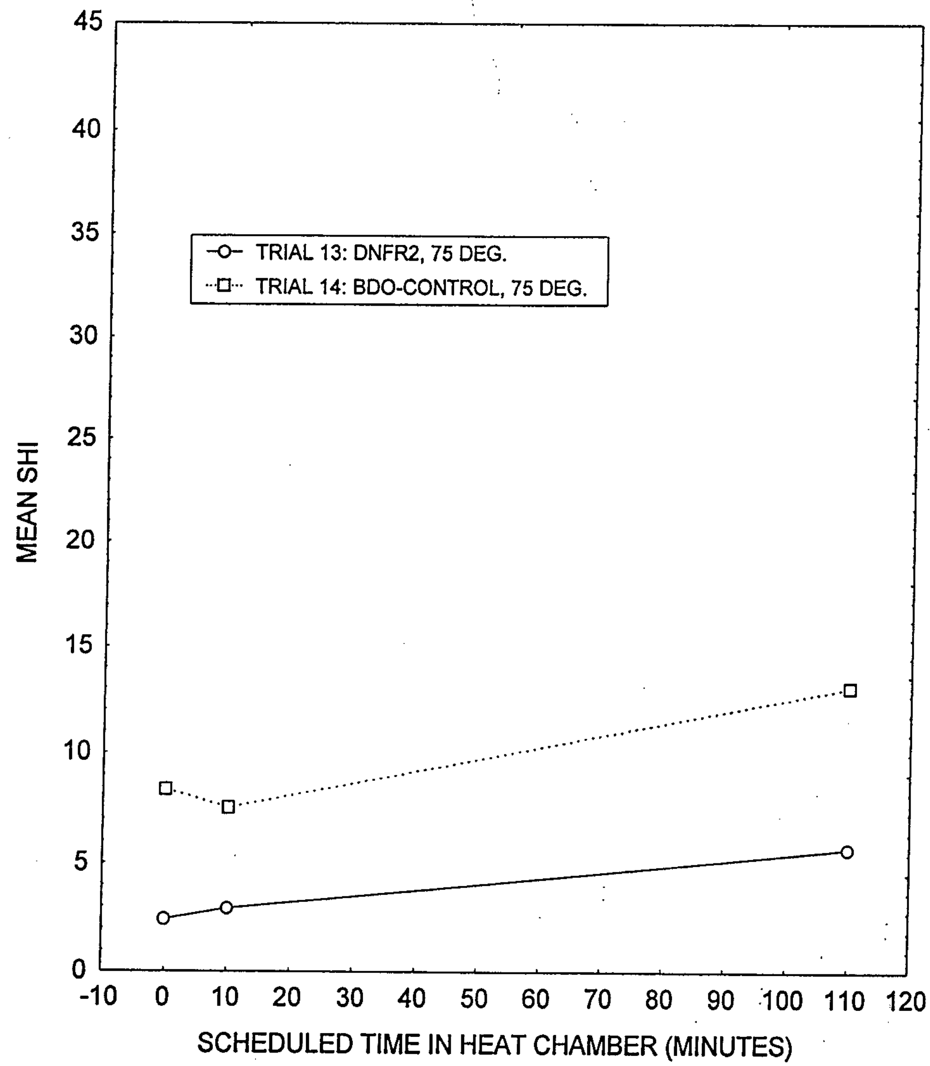
Sweating Rate and Evaporative Heat Loss: (see Figures 21 and 22) Neither total SR nor the % evaporated were significantly different between garments. The evaporative heat loss was significantly greater for garment 13.

Subjective Data Comparison of Garment Trial 13 (worst-case JSLIST-D-NFR2 at 75°) and Garment Trial 14 (BDO-Control at 75°) (n=12): There was a significant difference ($F(1,11)= 6.44$; $p <0.05$) between the SHI scores of Garment Trial 13 (3.67 $\pm$ 3.94 s.d.) and Garment Trial 14 (9.61 $\pm$ 10.35 s.d.). SHI scores were significantly higher in the BDO-Control garment. SHI scores were significantly higher ($F(2,22)=6.48$; $p < 0.01$) during the 100-minute-walk at 75° (9.33 $\pm$ 11.02 s.d.) as compared to SHI scores prior to entering the test chamber (5.38 $\pm$ 6.03 s.d.) or during the 10-minute-prewalk (5.21 $\pm$ 6.70 s.d.). There was no significant garment x administration interaction. See Figure 41.

Insert Figure 41 here

Figure 41

Plot of SHI Means by Scheduled Time in Chamber
2-way interaction
$F(2,22)=0.80; p=.46$



FIELD STUDY

METHODS

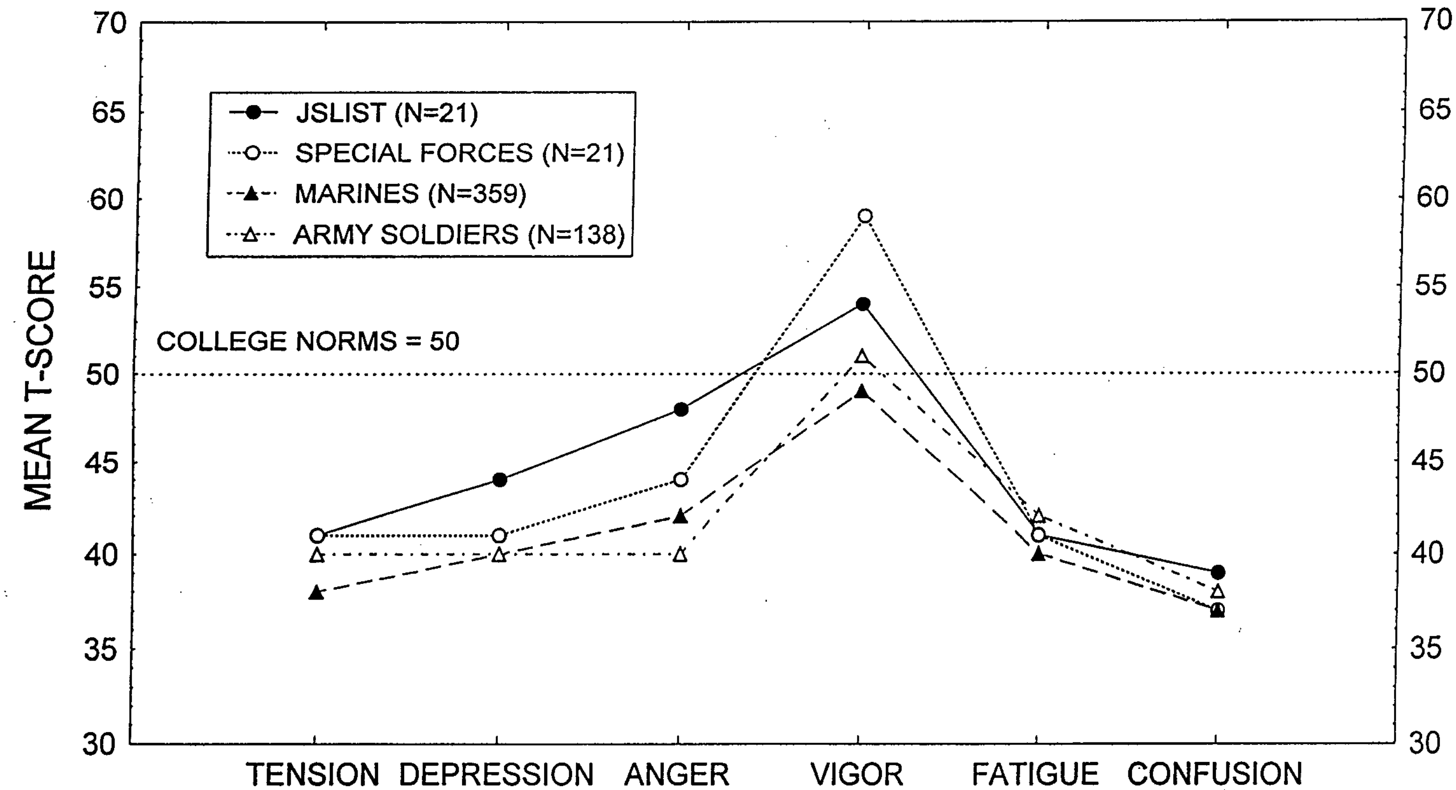
Subjects

Twenty-one healthy volunteers (17 male, 4 female), including 17 marines from the USMC base at Twentynine Palms CA and from Camp Pendleton CA, and 4 soldiers from the test volunteer platoon at Soldier Systems Command, Natick MA, participated as test subjects. They were divided into two groups. Group 1 (11 male, 1 female) tested garments 1-9 in the morning, and Group 2 (6 male, 3 female) tested garments 10-13 in the afternoon. The subjects' characteristics (mean, SD) were as follows: Group 1 (n=12) age 22 (2) yrs, height 178.5 (6.1) cm, weight 76.1 (8.4) kg, body fat 16.4 (5.3) %, body surface area 1.94 (0.11) m^2. Group 2 (n=9) age 21 (5) yrs, height 173.5 (10.5) cm, weight 79.7 (17.3) kg, body fat 21.7 (7.2), body surface area 1.94 (0.25) m^2. The POMS psychological mood scores were typical of military populations: the predominant mood was vigor with lower scores on tension, depression, anger, fatigue, and confusion. This "iceberg" profile of moods is presented in Figure 42. Dishman persistence motivation scores (mean = 160, s.d. = 16) were again higher than the college norms, which is typical of U.S. military samples such as Army War College students and Special Operations Forces.

Insert Figure 42 here

Figure 42

PROFILE OF MOOD STATES (POMS)



Experimental Design and Procedures

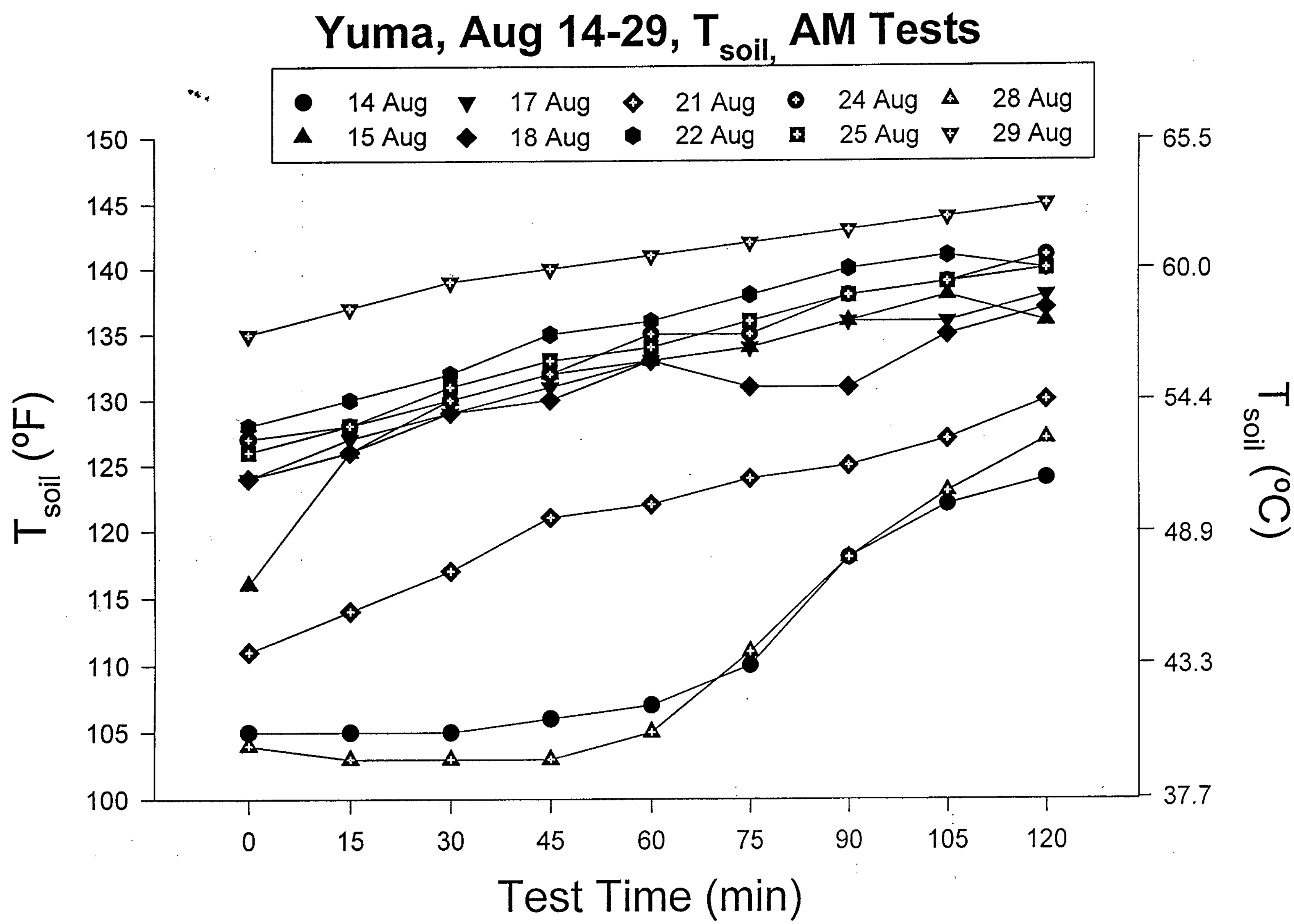
Because 13 different garment trials were attempted, and not all of them needed to be compared to one another, the trials were divided into two groups for testing with two groups of volunteers. One group of 12 volunteers attempted trials 1-9, and a separate group attempted trials 10-13. The first 9 trials all needed to be done by one group, as statistical comparisons were among garments 1-7 and 3, 6, 8 and 9. For the second group, trial 10 was compared to 11, and trial 12 to 13. (See Table 2.) For each group, the garment trials were counterbalanced so that no garment was at an advantage or disadvantage due to test order, ambient conditions or other possible variables in test conditions.

The volunteer Marines from Twentynine Palms, Camp Pendleton, and YPG had been living and working in a hot environment for at least the summer, and were naturally acclimatized to a hot desert environment (~80-115°F/20-60%rh). The volunteer Soldiers from Massachusetts had been living and working in an unusually hot summer in New England, and were assumed to be at least partially acclimatized. After their arrival in Yuma, all the volunteers were instructed to continue to participate in their routine daily physical training and informal outdoor activities (including walking, playing ball, etc.) until testing began (approximately 3-4 days after their arrival). There was no controlled acclimation program for any of the volunteers.

All testing was conducted at YPG during August of 1995. During garment tests, the ambient weather conditions (T_{db}, T_{bg}, T_{wb}, and wind speed) were closely monitored at the test site, and recorded every 15 min during the test sessions, to document conditions during testing. In addition, we obtained daily weather data from the YPG Meteorological Team, which included hourly data not only of temperatures and wind speed, but of soil temperature, radiation, wind direction and gust speeds. Each garment trial was 2 hours long consisting of two 40 min moderate and light-to-moderate exercise bouts, each followed by 20 min of rehydration, rest and sedentary activity. Volunteers tested 2-4 days per week. The ambient conditions during testing are illustrated in Figures 43a-b.

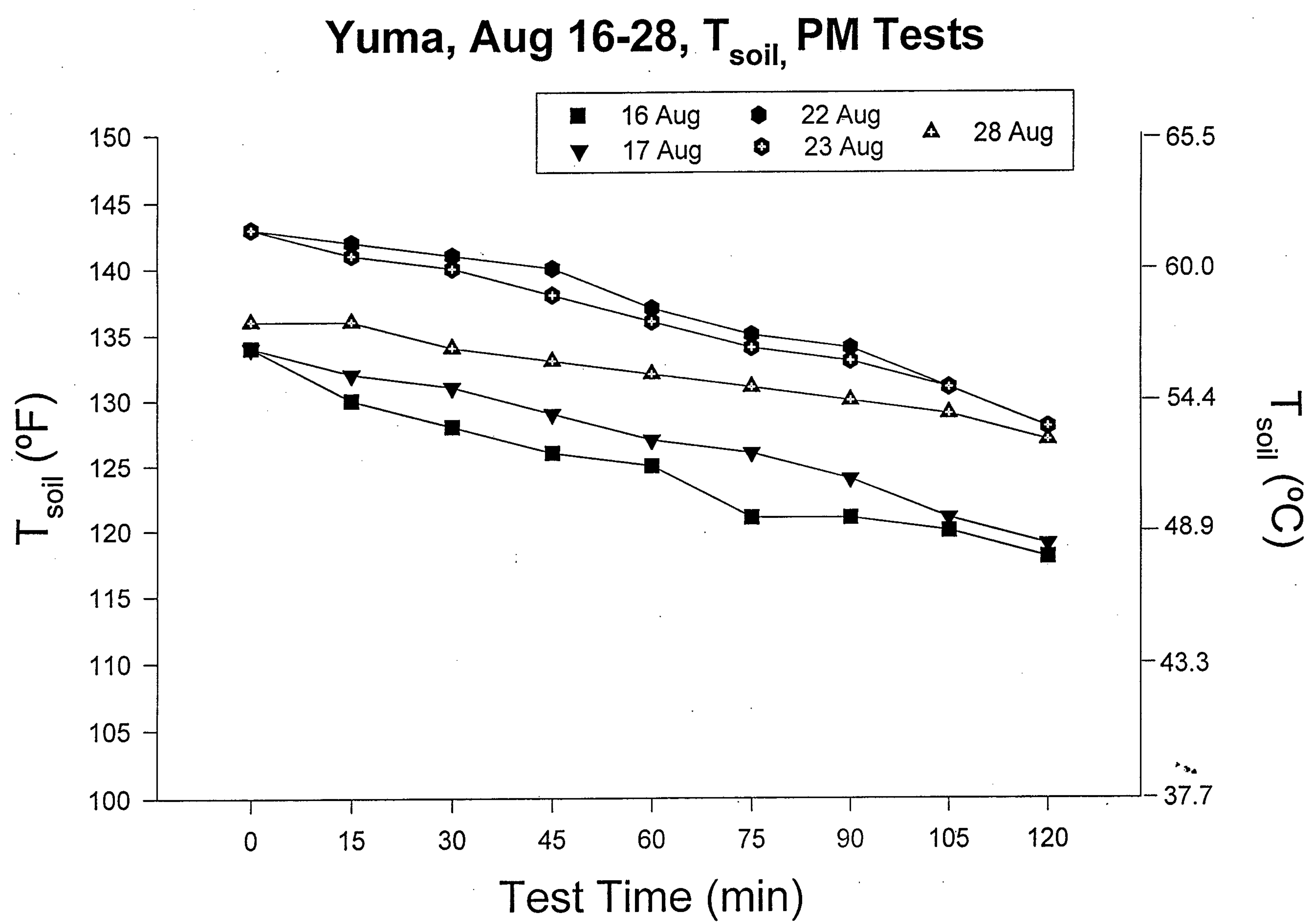
Insert Figures 43a and 43b here

Figure 43a



Yuma, Aug 14-29, T_{soil}, AM Tests
14 Aug
17 Aug
21 Aug
24 Aug
28 Aug
15 Aug
18 Aug
22 Aug
25 Aug
29 Aug
T_{soil} (°F)
150
145
140
135
130
125
120
115
110
105
100
0
15
30
45
60
75
90
105
120
Test Time (min)
65.5
60.0
54.4
48.9
43.3
37.7
T_{soil} (°C)

Figure 43b



Yuma, Aug 16-28, $T_{soil,}$ PM Tests
16 Aug
17 Aug
22 Aug
23 Aug
28 Aug
T_{soil} (°F)
150
145
140
135
130
125
120
115
110
105
100
0
15
30
45
60
75
90
105
120
Test Time (min)
T_{soil} (°C)
65.5
60.0
54.4
48.9
43.3
37.7

Each test day, in an air conditioned dressing area (inside the YPG clinic), after obtaining minimally dressed (with underwear/no t-shirt) weights and dry clothing weights, each subject was instrumented with a rectal thermistor (Yellow Springs Instruments) which they inserted ~10cm beyond the anal sphincter, a 4-point (chest, forearm, thigh and calf) skin temperature thermistor harness, and an elastic chest band electrode and watch receiver to monitor heart rate (Polar Vantage). T_{re} was displayed and T_{re} and T_{sk} were recorded on a Squirrel Datalogger. Just prior to transport to the test site, dressed weights and (full) canteen weights were taken and recorded. The subjects were driven to the test site in air conditioned vehicles where they waited ($\leq$ 5 min) until the test began. Figure 44 is a diagram representing the field test site.

The morning garment trials (group 1, trials 1-9) began as early as 10:20 and were completed no later than 12:50 each day (target time was 10:30-12:30). The afternoon garment trials (group 2, trials 10-13) began as early as 3:25 and were completed no later than 5:45 (target time was 3:30-5:30).

The first hour of the 2-hour test consisted of 40 min of "marching" (walking at 3 mph, which is considered moderate intensity exercise) on a mostly packed, mostly flat sand and gravel course in full sunlight, followed by 20 min of rest, rehydration, and sedentary activity (questionnaires) at a shaded area. Subjects were dressed in MOPP level 2 during the first hour. (MOPP 2: CB garment opened, overboots on, mask, hood, gloves carried, duty uniform hat on.)

The second hour of the 2-hour test began with a simulated nuclear-biological-chemical (NBC) alert in which the subjects donned MOPP level 4 (don protective mask, hood and gloves, close garment openings) and also donned the helmet. Within 5 min they began a simulated NBC Reconnaissance procedure and continued (light-moderate intensity exercise) for 35 min. For the purpose of our test, the simulated NBC Reconnaissance consisted of walking segments of the course, and stopping for 5 min at designated areas as if using a detector kit to search for signs of chemical agent contamination. (No chemical agents were used during this study.)

The subjects were allowed to drink water or a sport drink *ad libitum* during testing, but were encouraged to drink one canteen full (1 L) each hour. Dressed weights were measured at the rest breaks. After the first hour we assumed garments contained a

steady-state volume of unevaporated sweat (1 L), as determined during previous research with two of the control garments (CPU and BDO; Levine et al, 1993) which approximated the range for garments in this study. We attempted to account for the unevaporated sweat in the garments when we estimated hydration status/dehydration level during the first rest break. If we estimated a subject was equal to or more than 1% dehydrated, we strongly encouraged them to drink.

Physiological Measurements. During testing heart rate (HR) was obtained from the portable heart rate "watches" (Polar Vantage) and was monitored and recorded at 5-min intervals. Rectal temperature (T_{re}) was measured using a flexible thermistor thermometer (Yellow Springs Instruments, YSI) inserted approximately 10 cm beyond the anal sphincter, and monitored every 5 min on a portable data acquisition unit (squirrel: Grant squirrel digital meter/logger) which continuously collected and stored the data for later downloading. T_{sk} was measured by thermistors (YSI) taped to the skin at 4 sites (chest, calf, thigh, forearm). These were also connected to the squirrel datalogger. Mean weighted skin temperature ($\bar{T}_{sk}$) was calculated from the stored data (Ramanathan, 1964). Whole body sweating rate and evaporative sweating were estimated from changes in minimally clothed weights taken before and after the tests, from garment weights taken before and after the tests, and from dressed weights taken before, during (at the first 20-min rest break), and after the tests. Corrections were made for water ingested, voided and trapped in the garments. Due to technical problems with the scales on the first test day, no statistical analyses were performed on the sweating rate data.

Subjective Measurements. For each of the 13 garment trials, the test volunteers were administered the SHI three times: once prior to the first exercise bout, once after the first 40-min exercise bout, and again after the second exercise bout. The SHI was scored in accordance with standard procedures (Johnson & Merullo, 1993), and comparative analyses were made of the trial garments according to the overall design of the study.

Statistical Analyses. Sample size estimation (α=0.05, β=0.20, based on data from the Saratoga garment) determined that a minimum of 11 test subjects were needed for our garment comparisons (Borenstein & Cohen, 1988). Multifactor analysis of variance (subject x garment x time) was used to analyze data for the physiological variables

measured. With one group of test subjects as their own controls in a counterbalanced study design, garments 1-9 were compared (garments 1-7 and 8-9 were also compared as these were subgroups within the larger group of comparisons). With another group of test subjects as their own controls, in a counterbalanced test design, garments 10-11 and 12-13 were compared separately. Where significant main effects or interactions were found, Tukey's test of critical difference was used to locate significant differences ($p<0.05$).

Figure 44

JSLIST Heat Stress Test

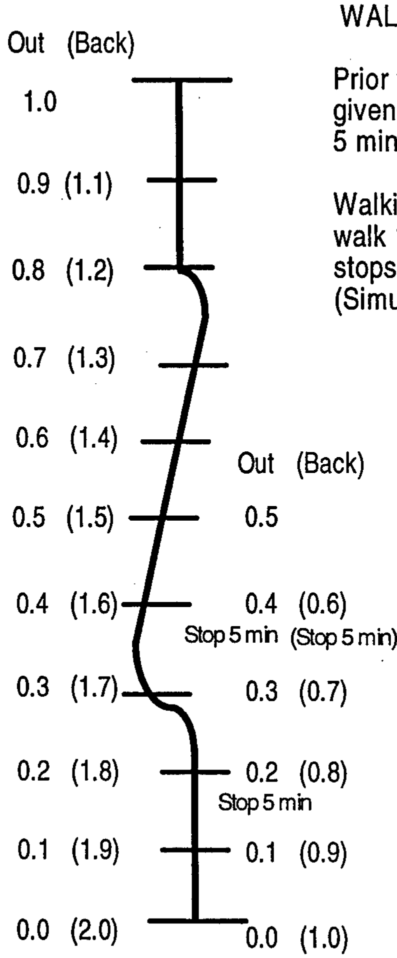
August 1995 at Yuma Proving Ground, AZ

Field-Test Course:
Out and back on a mostly flat, packed sand road.
(no shade except at tarp area)

WALK / REST 1 (MOPP 2)

Total time for Walk 1 = 40 min
20 min per mile (3 mph) pace
(2 min between markers)
Begin at shaded tarp area,
walk out 1 mile, back 1 mile.

After Walk 1, there is a 20 min seated rest in the shade. Canteens are weighed & refilled, subjects are weighed, and questionnaires are answered.



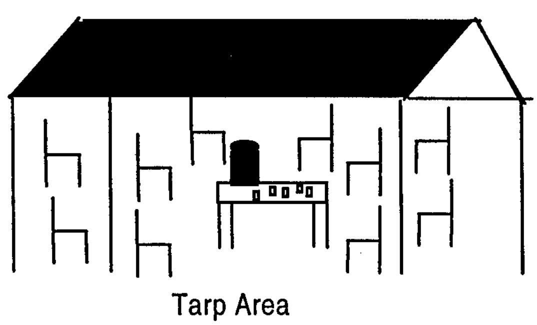
WALK / REST 2 (MOPP 4)

Prior to Walk 2, subjects are given "NBC alert" and have 5 min to don MOPP 4

Walking pace is the same as walk 1 but there are three 5-min stops at 0.2 mi, 0.4 mi, & 0.6 mi. (Simulated NBC reconnaisance).

After Walk 2, subjects remain in MOPP 4 for 20 min in the shaded tarp area to rest, etc. (as during the rest after Walk 1).

TEST ENDS



Tarp Area

Test begins and ends at tarp area.
Tarp area is used for shade, seated rest, rehydration, body & canteen weights, & questionnaires.

Description and Timetable of the YPG Field Test

0-40 min = 40 min walk 1 in the sun (MOPP 2: garments opened, duty uniform cap on, overboots on, carry mask, gloves, hood if not integral), consisting of 3 mph walk on a gravel road (1 mile out/1 mile back). Wear pistol belt and two (full at beginning of walk 1) 1-liter canteens.

40-60 min = 20 min rest in the shade (MOPP 2) consisting of rest, rehydration (weigh and refill canteens), answer SHI questionnaires, use latrine if necessary, mid-test dressed weights.

60-65 min = 5 min stand in the sun, don MOPP 4. Also wear pistol belt and two (full at beginning of walk 2) 1-liter canteens.

65-100 min = 35 min walk 2 in the sun (MOPP 4: garment openings are closed, mask and hood on, gloves on, helmet on), consisting of 3 mph walk on gravel road .2 mile (4 min) then stop 5 min (simulate chemical survey), walk .2 mile (4 min) then stop 5 min, walk .2 mile (4 min) then stop 5 min, walk .4 mile (8 min) to rest area.

100-120 min = 20 min rest in the shade (MOPP 4) consisting of rest, rehydration (weigh and refill canteens if necessary), answer SHI questionnaires, use latrine if necessary, post-test dressed weights.

RESULTS

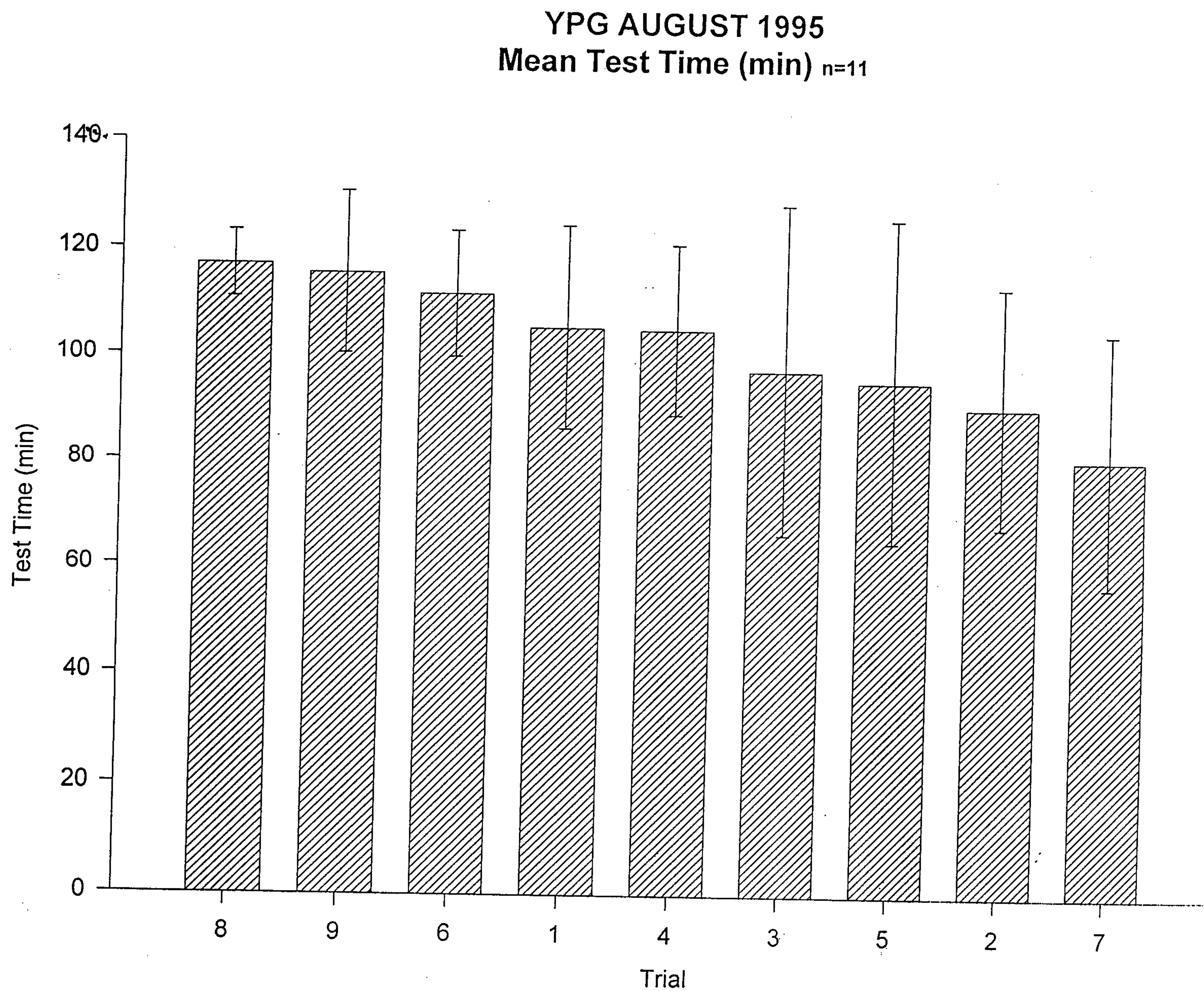
Because of the effects of heat stress in this study, few test subjects were able to complete the entire 120 min for most of the garment trials. The statistical analyses of the physiological variables for each garment comparison were performed on data through the longest time that enough subjects for comparison were still testing. In some cases, additional analyses were made for fewer subjects who were able to remain in the tests for a longer time. The number of subjects included is reported for each comparison. In no cases were there enough subjects left testing to perform statistical analyses to include the entire 120 min test.

Garment Trials 1-9

When mean test times were compared among garment trials, trials 8, 9 and 6 were significantly longer than trial 7 ($p<0.01$). The garments worn as duty uniforms (trials 8 and 9, not significantly different from one another), and the Saratoga control worn over the TBDU (trial 6) allowed subjects to remain testing significantly longer than the Battledress Overgarment (trial 7) did. These results are consistent when trials 1-7 and trials 8 vs 9 were analyzed separately. Test times were not significantly different among the JSLIST overgarments (trials 1-5), or between them and the controls. Table 6 lists the garment trials along with the means (±SD) for test times, and for T_{re} and HR at 60 min. Figure 45 illustrates the test times for garments 1-9.

Insert Figure 45 here

Figure 45


YPG AUGUST 1995
Mean Test Time (min) n=11
Test Time (min)
0
20
40
60
80
100
120
140
8
9
6
1
4
3
5
2
7
Trial

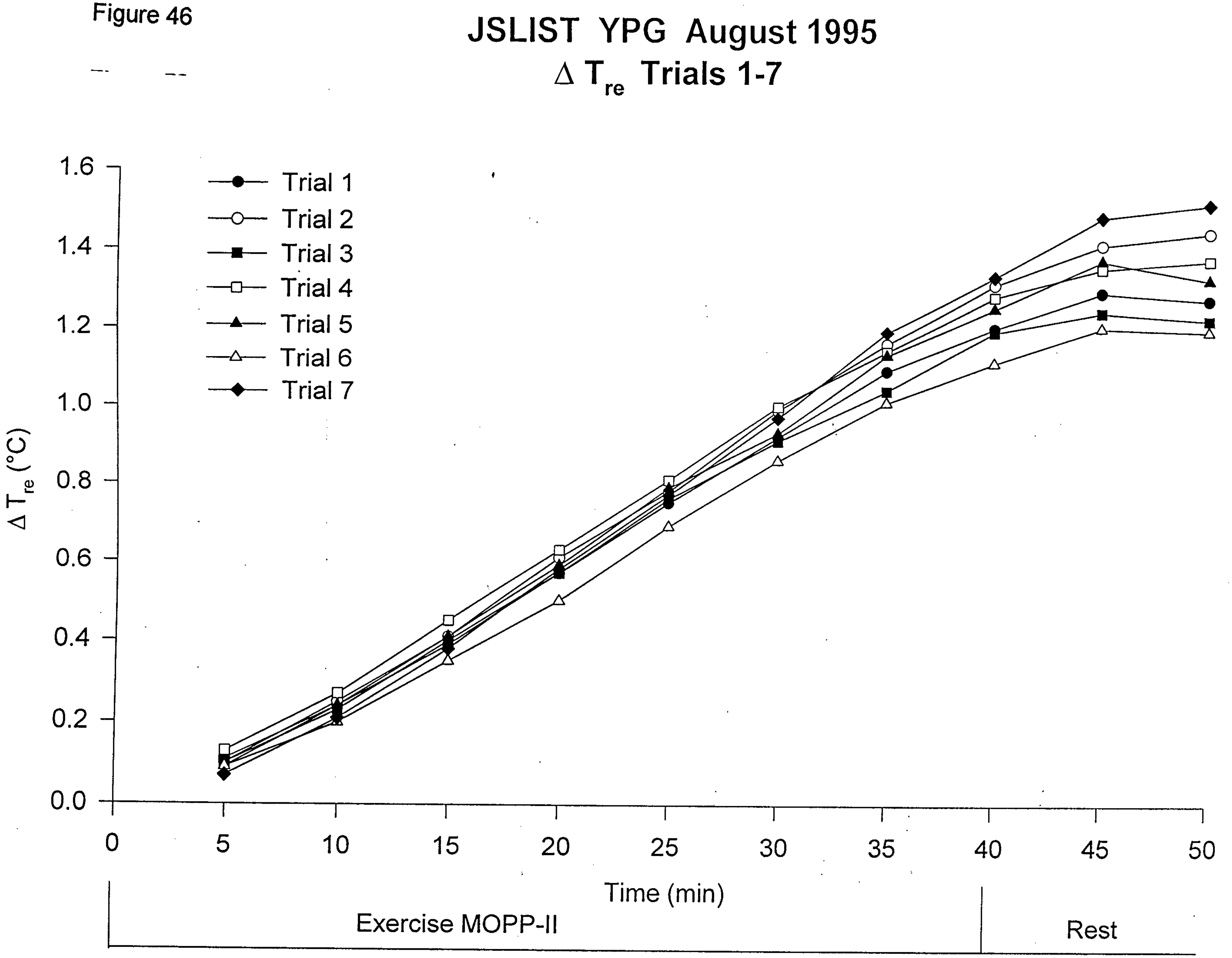
When rectal temperatures were compared among Garment Trials 1-7 (n=8 to 50 min, no figure), by 35 min, through 50 min, they were significantly ($p<0.05$) higher in trial 2 (JSLIST OFR2) than in all other trials except trial 7 (BDO). By 35 min (through 50 min), T_{re} during trials 2 and 7 were significantly higher than during trials 3 (JSLIST ONFR 1) and 6 (SAR). For analyses at minutes 45 and 50, T_{re} were higher during trials 2 and 7 than during trials 4, 1, 3, and 6. During all garment trials, T_{re} increased significantly over time.

When the change in rectal temperature (ΔT_{re}, from time 0 min to each 5-min value, Figures 46 and 47) was analyzed, trial 7 caused the largest increase in T_{re}, trial 2 is next, while trial 6 caused the smallest increase in T_{re} among trials 1-7. By min 35, ΔT_{re} for trial 7 was significantly greater than that for trial 6. By 40 min, ΔT_{re} for trials 7, 2, and 4 were greater than 6, by 45 min 7 and 2 were greater than 3 and 6, while 7, 2, and 5 were greater than 6. By 50 min ΔT_{re} for trial 7 was greater than 1, 3, and 6, while 7 and 2 were greater than 3 and 6, and 7, 2, and 4 were greater than 6. When trials 8 and 9 (JSLIST Duty Uniform and SAR with no duty uniform) were included in the analyses, ΔT_{re} were significantly lower in trials 8 and 9 than ΔT_{re} for all other trials, but there were no differences between trials 8 and 9. ΔT_{re} increased significantly over time in all trials.

Analyses of $\bar{T}_{sk}$ (n=7 to 50 min, no figure) indicate that at min 30, 35 and 50, $\bar{T}_{sk}$ was significantly hotter in garments 7 and 2 compared to garment trial 3. In addition, at min 35 and 50, $\bar{T}_{sk}$ in garment trials 4, 2, and 1 were also hotter than those in trial 3 (at 50 min trial 5 $\bar{T}_{sk}$ were also hotter than 3). At all other 5-min intervals $\bar{T}_{sk}$ were not significantly different among trials. The highest $\bar{T}_{sk}$ occurred at min 45. The order of garment trials from hottest to coolest (no significant differences at 45 min) were 4, 7, 2, 5, 6, 1, 3. For garment trials 8 and 9, $\bar{T}_{sk}$ were not different for analyses to 50 min (n=12), 70 min (n=11), or 100 min (n=10). When trials 1-9 were compared, $\bar{T}_{sk}$ were cooler for subjects in trials 8 and 9 compared to all other trials but 3 at 45 min, and cooler than trial 7 from 20 min on. By 30 min, $\bar{T}_{sk}$ for trials 7, 2, 4 and 1 were hotter than $\bar{T}_{sk}$ for trials 8 and 9. Differences among the prototype garments were significant at 40 min, where $\bar{T}_{sk}$ for trials 7, 1, 2, 4 > 3, 8, 9, and at 35 min where $\bar{T}_{sk}$ for trials 7, 4 and 2 >3, 8 and 9. $\bar{T}_{sk}$ increased significantly over time in all trials, however, for trials 8 and 9 significant increases occurred only through the first 20 min of testing.

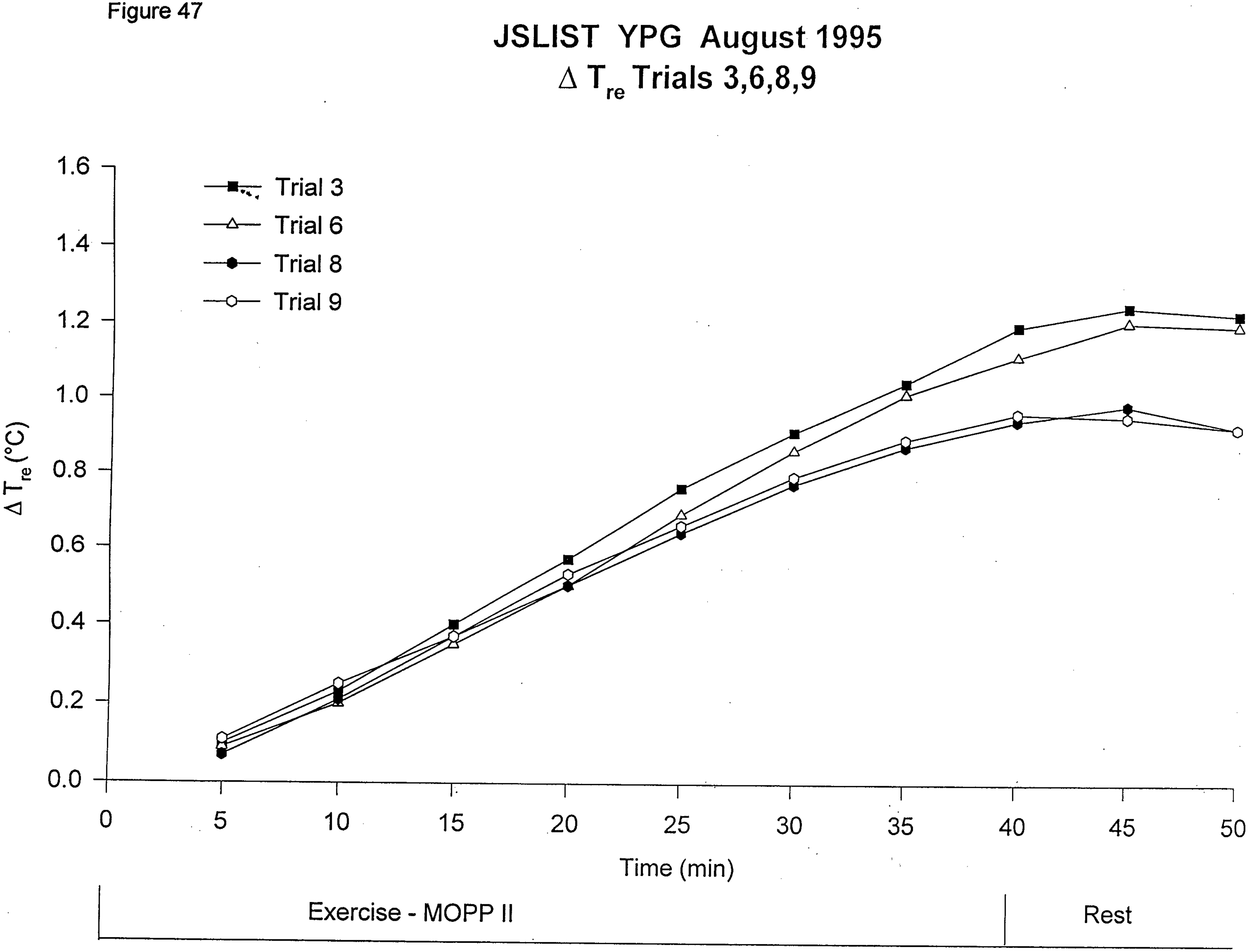
Insert Figures 46 and 47 here

Figure 46



JSLIST YPG August 1995
Δ T_{re} Trials 1-7
Trial 1
Trial 2
Trial 3
Trial 4
Trial 5
Trial 6
Trial 7
Δ T_{re} (°C)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0
5
10
15
20
25
30
35
40
45
50
Time (min)
Exercise MOPP-II
Rest

Figure 47



JSLIST YPG August 1995
Δ T_{re} Trials 3,6,8,9
Δ T_{re} (°C)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Trial 3
Trial 6
Trial 8
Trial 9
0
5
10
15
20
25
30
35
40
45
50
Time (min)
Exercise - MOPP II
Rest

Analysis of heart rates (Figures 48 and 49) show that HR during Garment Trials 8 and 9 were not different from each other and were lower than HR for all other trials from time 30 min to the end of analyses (40 and 50 min, n=7). Garment Trials 7 and 2 elicited the highest heart rates from 25 through 50 min. HR increased significantly over time in all trials.

Insert Figures 48 and 49 here

Figure 48

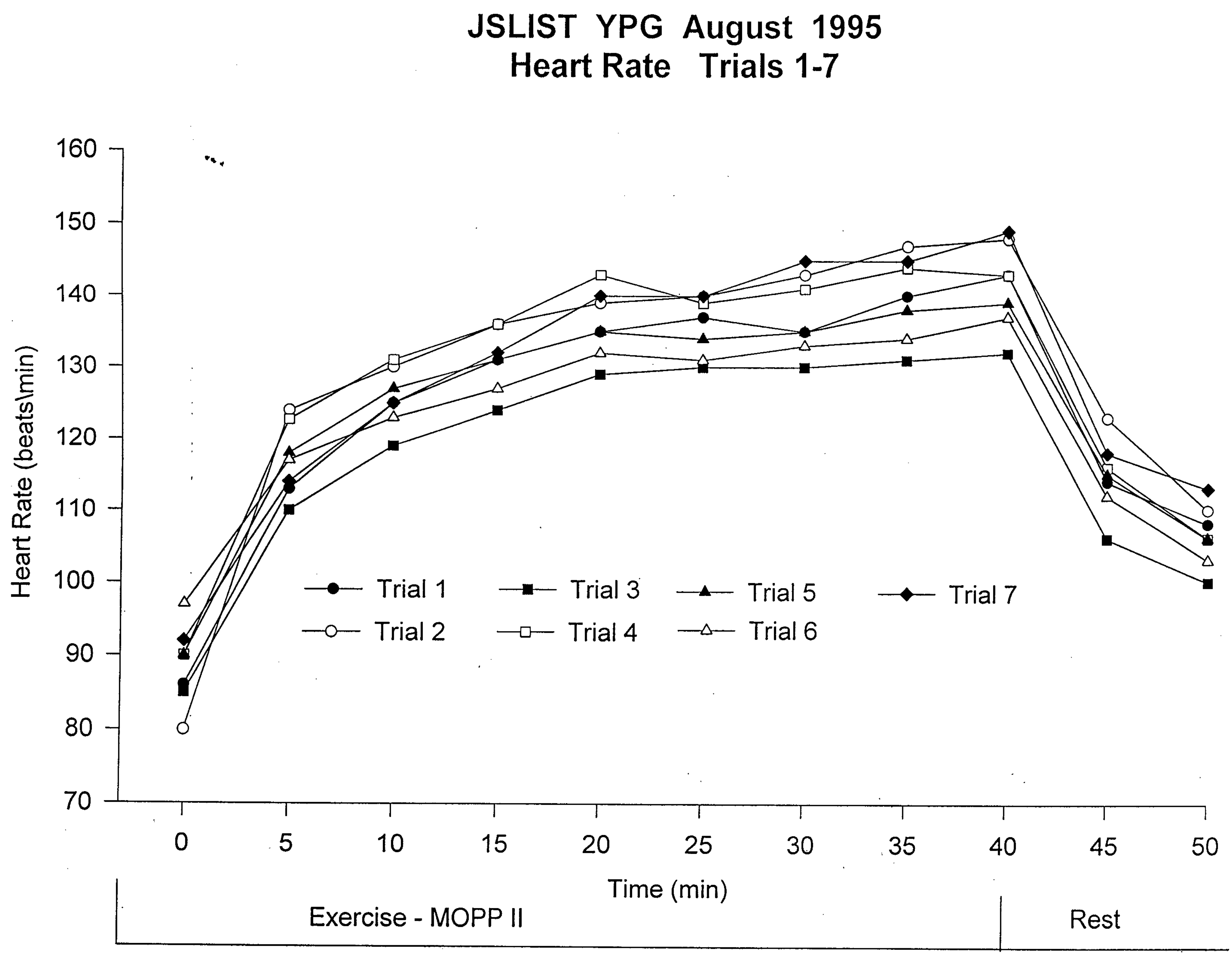
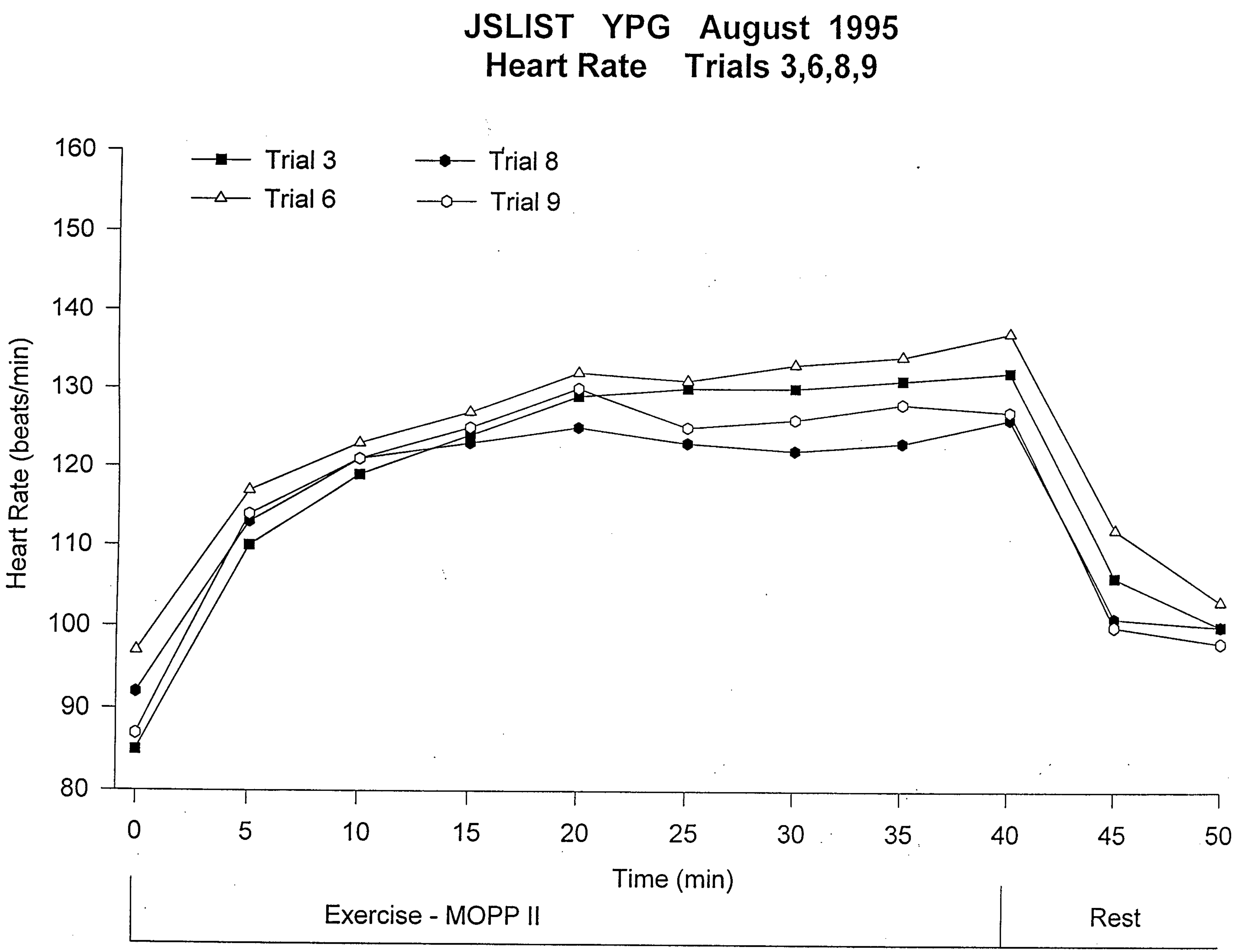

JSLIST YPG August 1995
Heart Rate Trials 1-7
Heart Rate (beats\min)
160
150
140
130
120
110
100
90
80
70
Trial 1
Trial 2
Trial 3
Trial 4
Trial 5
Trial 6
Trial 7
0
5
10
15
20
25
30
35
40
45
50
Time (min)
Exercise - MOPP II
Rest

Figure 49



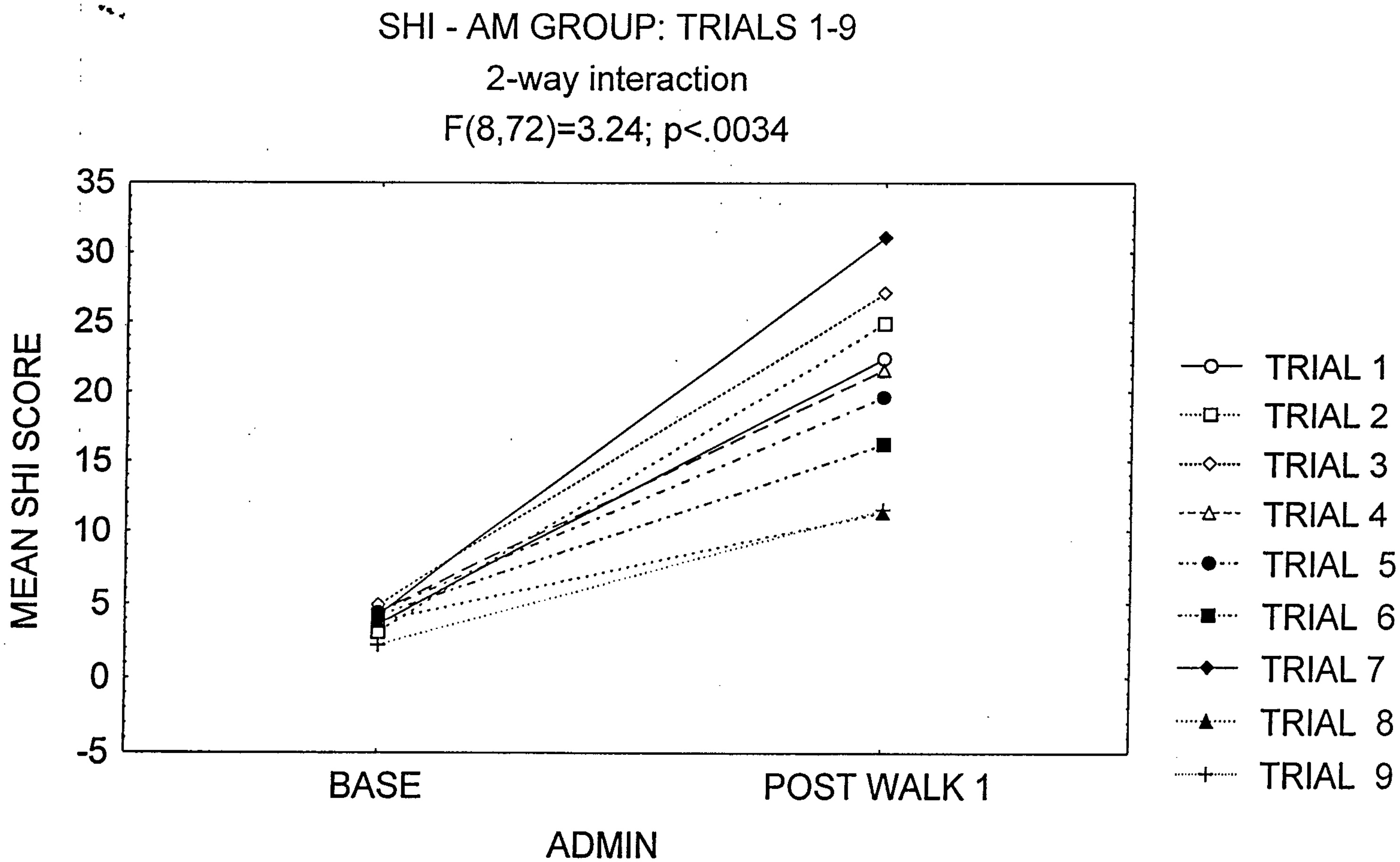
JSLIST YPG August 1995
Heart Rate Trials 3,6,8,9
Trial 3
Trial 6
Trial 8
Trial 9
Heart Rate (beats/min)
160
150
140
130
120
110
100
90
80
0
5
10
15
20
25
30
35
40
45
50
Time (min)
Exercise - MOPP II
Rest

Subjective data comparisons among the first 9 test garments were achieved by means of a 9 x 3 (garment x administration) repeated measures analysis of variance on the SHI scores; garments 1-7 and 8-9 were subjected to separate ANOVA's as these are meaningful subgroups within the larger group of comparisons. While nearly all subjects were able to complete the first hour's walk for all conditions, the number of volunteers who were able to complete both walks was much smaller. In order to take advantage of the larger N during the first hour, a separate series of ANOVA's was performed on the first two administrations only.

Garments 1-9: The results of the ANOVAs, graphically presented in Figures 50 and 51, indicate that when all 9 garments were compared to one another, during the first hour's walk (N=10) Garment 7 (BDO control) induced the severest SHI score and was significantly more severe than Garments 8 and 9 (JSLIST duty uniform and the SAR). The other Garments were neither significantly different from one another nor from the BDO Control (Figure 50). When results of the second walk were added into the analysis (N=3), the JSLIST duty uniform and the SAR again imposed the least subjective heat illness, while the BDO control (along with the OFR1, Garment 1) imposed the most (Figure 51). In both analyses, SHI scores increased significantly with each hour of walking in the heat.

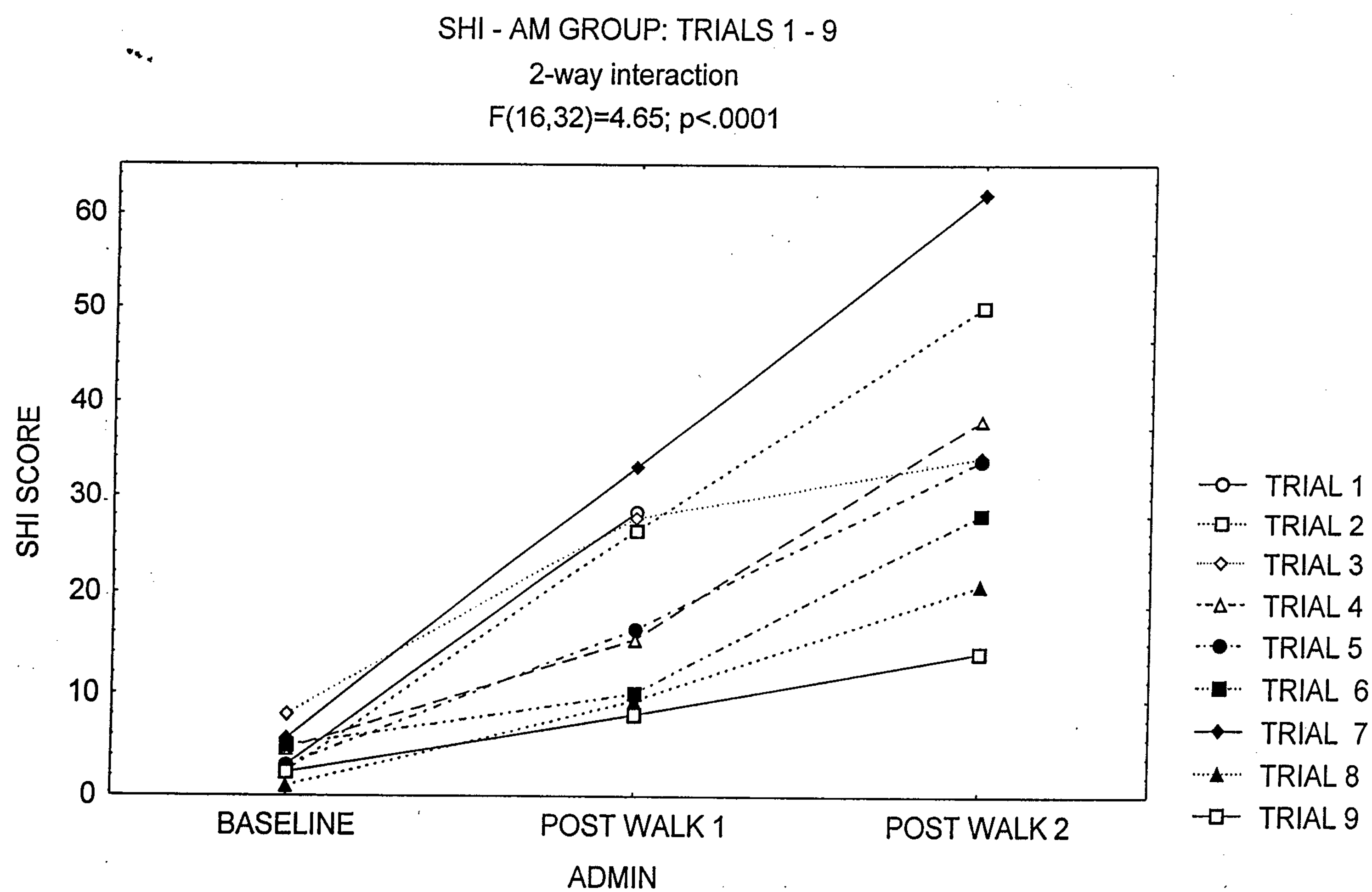
Insert Figures 50 and 51 here

Figure 50



SHI - AM GROUP: TRIALS 1-9
2-way interaction
F(8,72)=3.24; p<.0034
MEAN SHI SCORE
35
30
25
20
15
10
5
0
-5
BASE
POST WALK 1
ADMIN
TRIAL 1
TRIAL 2
TRIAL 3
TRIAL 4
TRIAL 5
TRIAL 6
TRIAL 7
TRIAL 8
TRIAL 9

Figure 51



SHI - AM GROUP: TRIALS 1 - 9
2-way interaction
F(16,32)=4.65; p<.0001
SHI SCORE
0
10
20
30
40
50
60
BASELINE
POST WALK 1
POST WALK 2
ADMIN
TRIAL 1
TRIAL 2
TRIAL 3
TRIAL 4
TRIAL 5
TRIAL 6
TRIAL 7
TRIAL 8
TRIAL 9

Garments 1-7: The results of the ANOVAs, graphically presented in Figures 52 and 53, indicate that when the first 7 garments were compared to one another, during the first hour's walk (N=10) Garment 7 (BDO control) again had the severest SHI score but it was not significantly more severe than any of the other garments. When results of the second walk were added into the analysis (N=3), the ONFR3 and SAR Control (Garments 5 and 6) imposed the least subjective heat illness, while the OFR1 and BDO Control (Garments 1 and 7) imposed the most. In both analyses, SHI scores increased significantly with each hour of walking in the heat.

Insert Figures 52 and 53 here

Figure 52

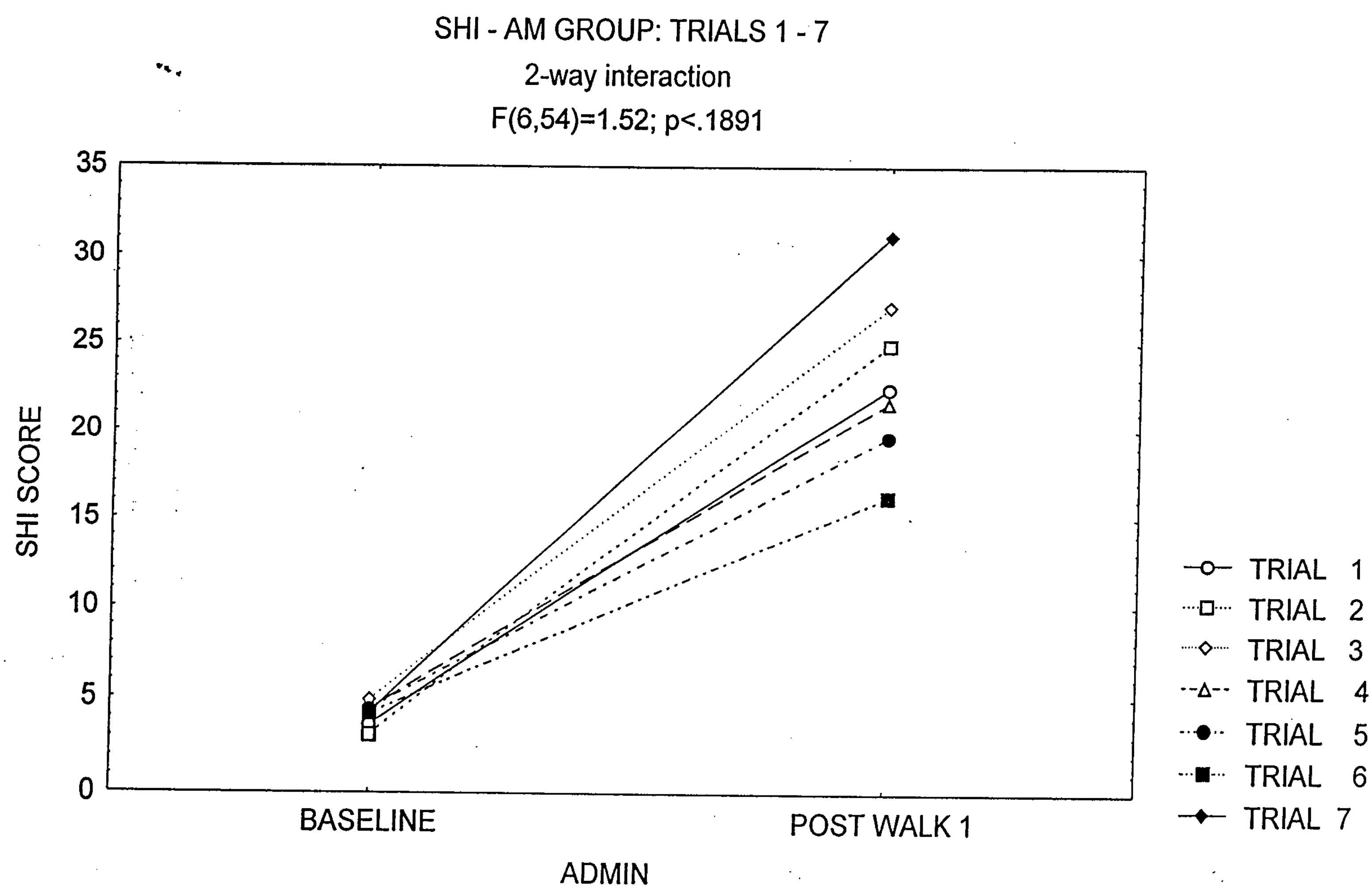
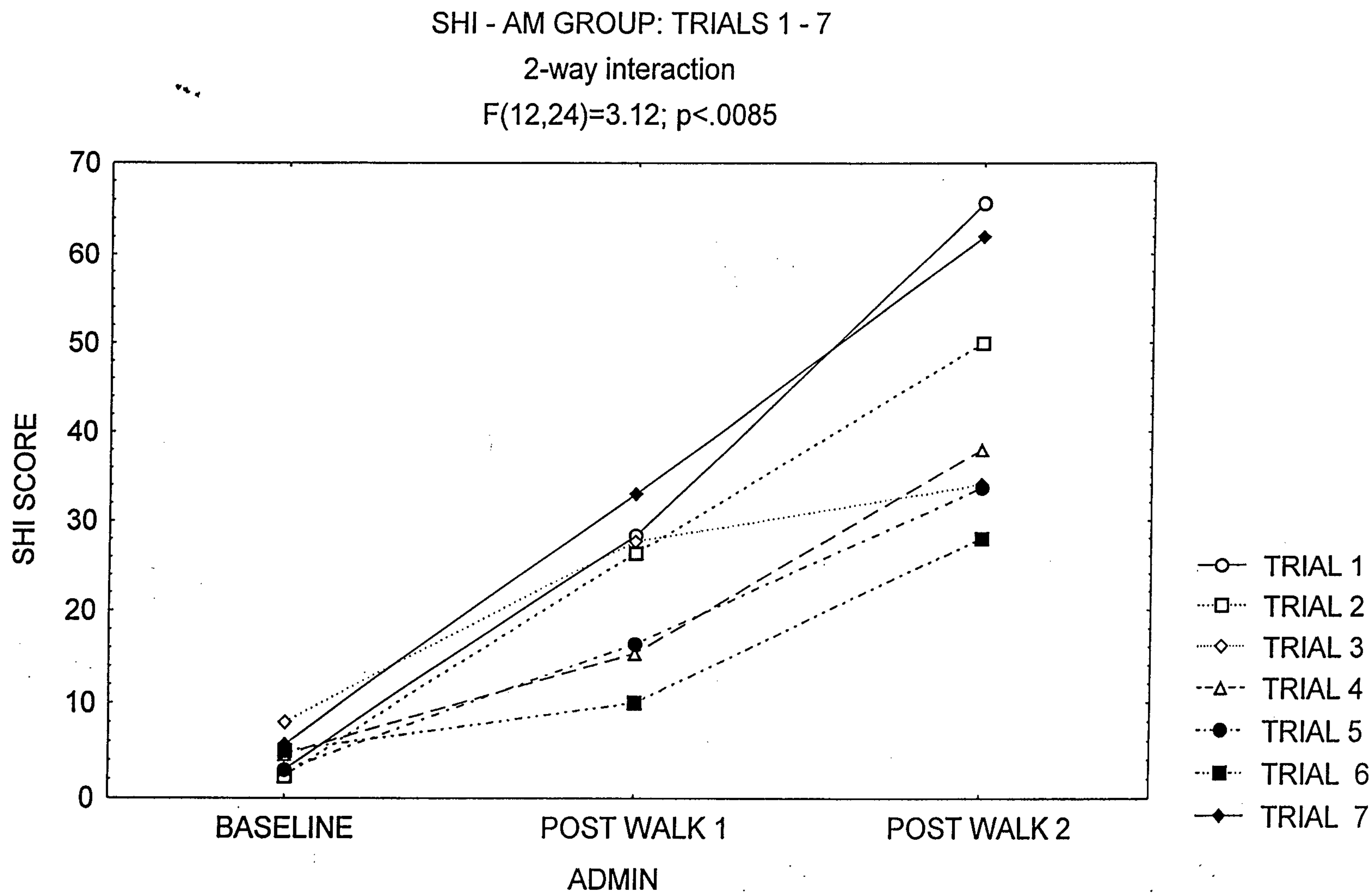

SHI - AM GROUP: TRIALS 1 - 7
2-way interaction
F(6,54)=1.52; p<.1891
SHI SCORE
35
30
25
20
15
10
5
0
BASELINE
POST WALK 1
ADMIN
TRIAL 1
TRIAL 2
TRIAL 3
TRIAL 4
TRIAL 5
TRIAL 6
TRIAL 7

Figure 53



SHI - AM GROUP: TRIALS 1 - 7
2-way interaction
F(12,24)=3.12; p<.0085
SHI SCORE
70
60
50
40
30
20
10
0
BASELINE
POST WALK 1
POST WALK 2
ADMIN
TRIAL 1
TRIAL 2
TRIAL 3
TRIAL 4
TRIAL 5
TRIAL 6
TRIAL 7

Garments 8 and 9: The results of the ANOVAs, graphically presented in Figures 54 and 55, indicate that when Garments 8 and 9 (SAR Control and JSLIST duty uniform) were compared to one another, during the first hour's walk (N=11) the garments did not differ from one another. When results of the second walk were added into the analysis (N=11), the two garments still did not differ from one another. In both analyses, SHI scores increased significantly with each hour of walking in the heat.

Insert Figures 54 and 55 here

Figure 54

SHI - AM GROUP: TRIALS 8 AND 9

2-way interaction

$F(1,10)=2.69; p<.1323$

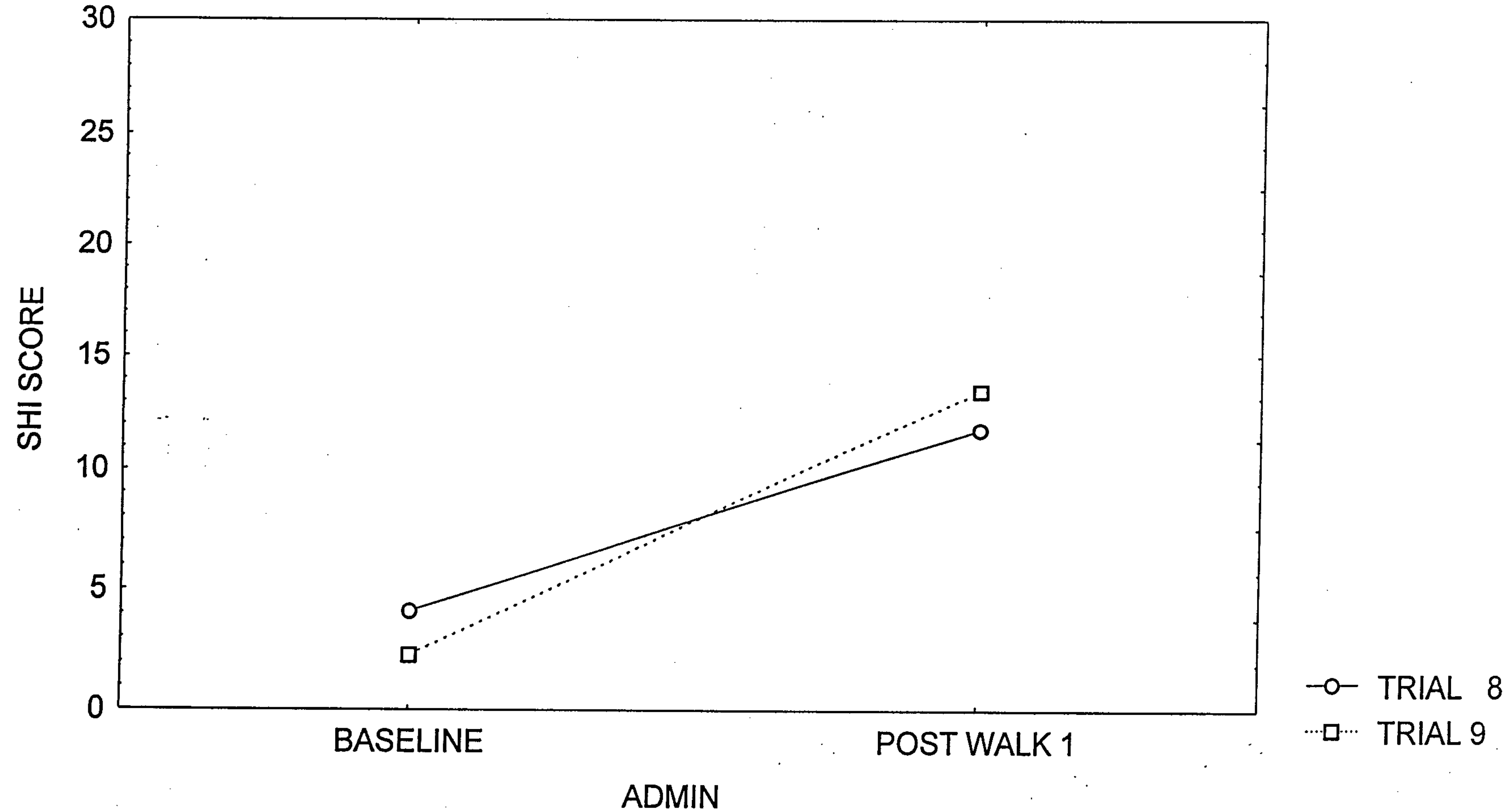
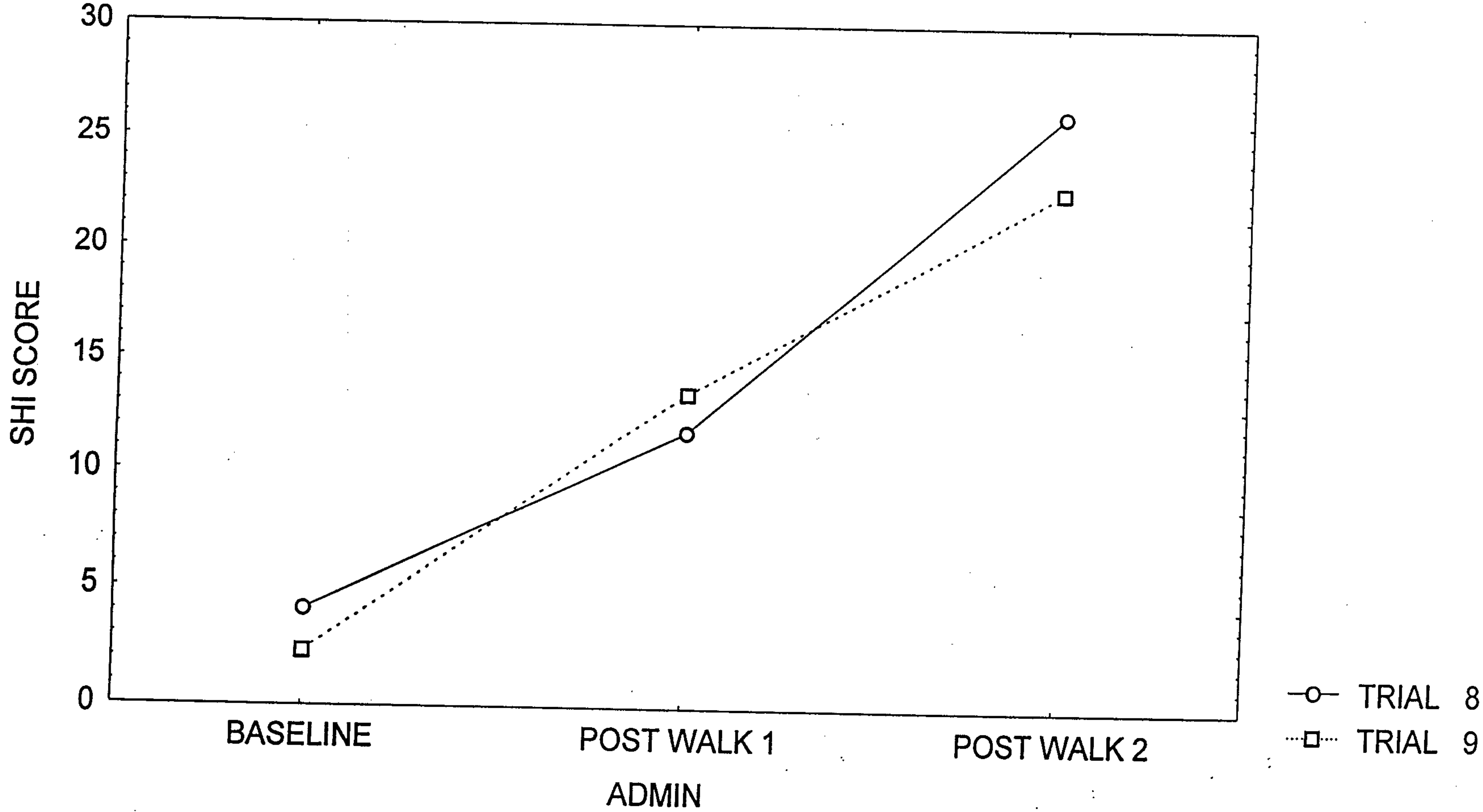


Figure 55

SHI - AM GROUP: TRIALS 8 AND 9
2-way interaction
$F(2,20)=1.22; p<.3164$

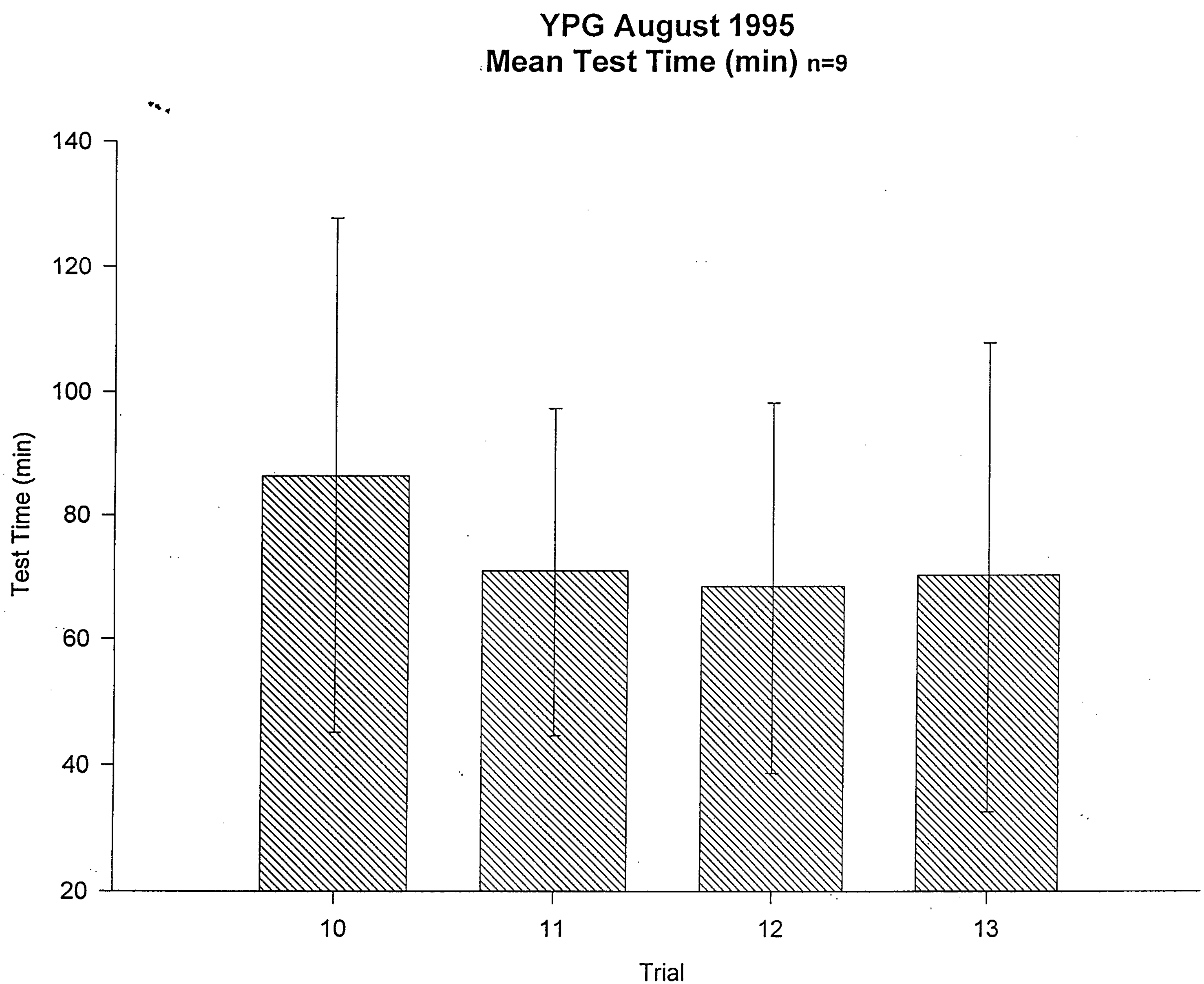


Garment Trials 10-11

Test times (Figure 56) for garment trials 10 and 11 (JSLIST VPFRU and CPU control) were not significantly different. T_{re}, ΔT_{re} (Figure 57), $\bar{T}_{sk}$, and HR (Figure 58) analyzed to 40 min (n=8) were also not significantly different between trials, but each variable increased significantly over time in both trials.

Insert Figure 56 here

Figure 56



YPG August 1995
Mean Test Time (min) n=9
Test Time (min)
140
120
100
80
60
40
20
10
11
12
13
Trial

Figure 57

JSLIST YPG August 1995
ΔT_{re} Trials 10 & 11

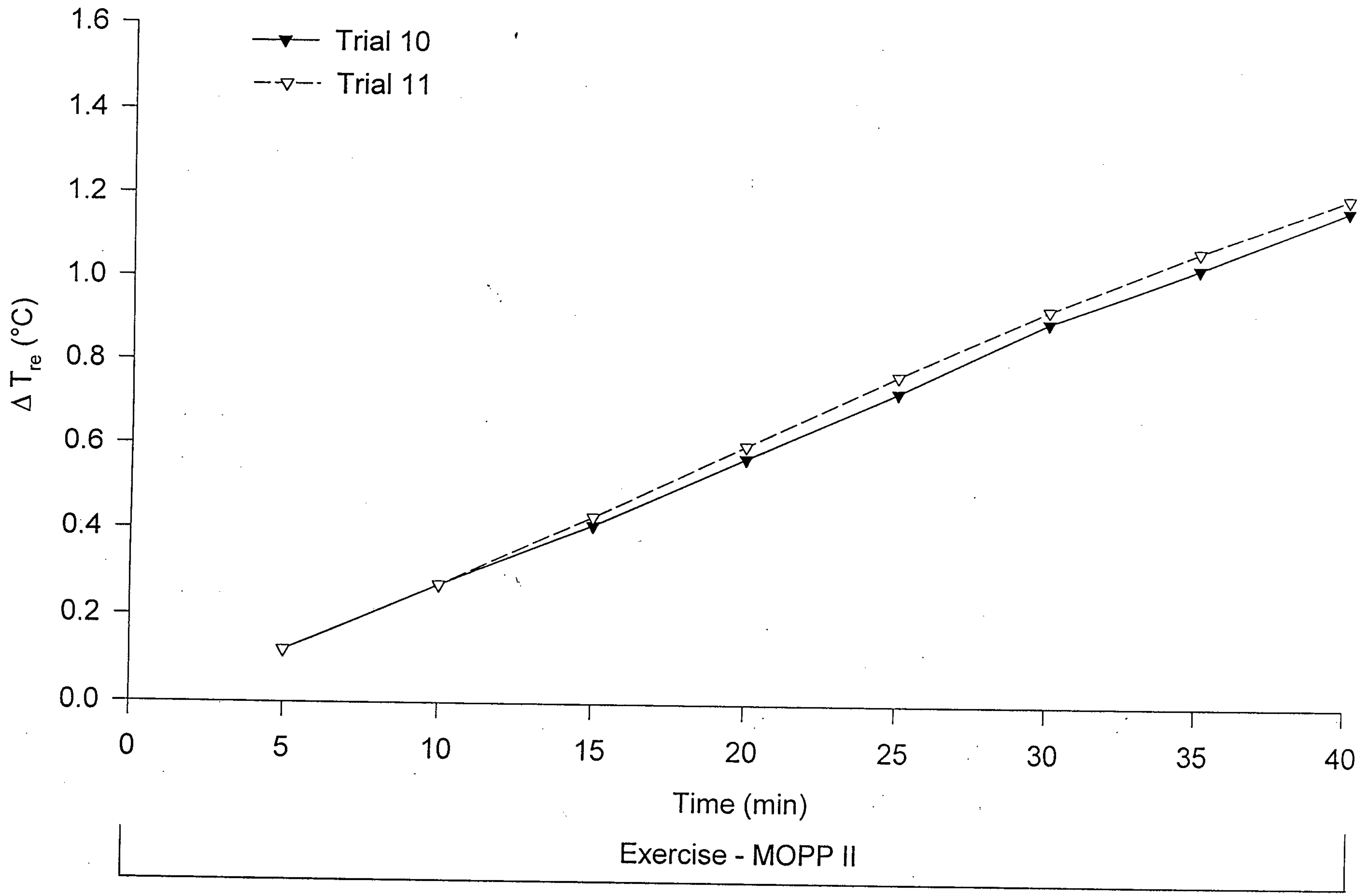
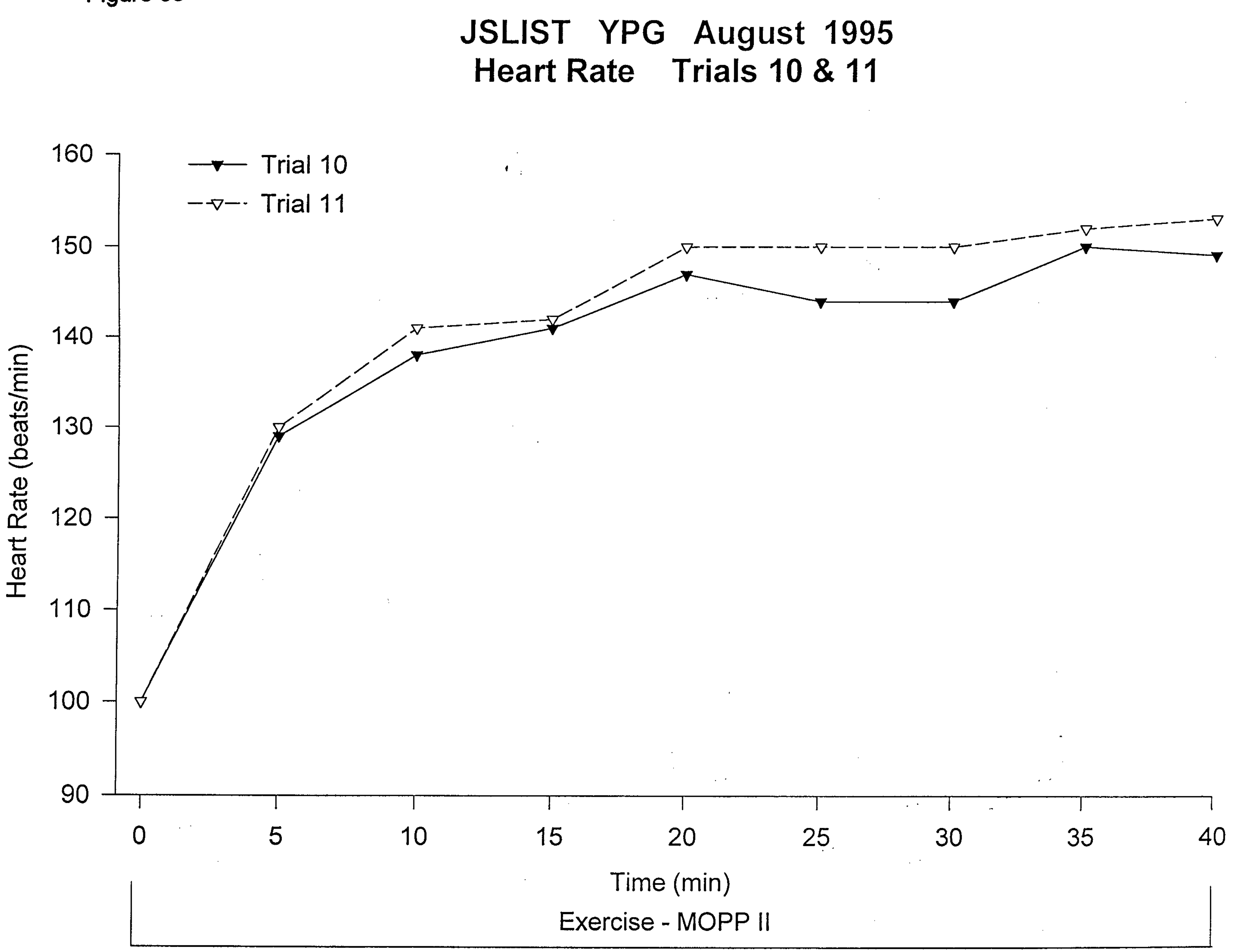


Figure 58


JSLIST YPG August 1995
Heart Rate Trials 10 & 11
Trial 10
Trial 11
Heart Rate (beats/min)
160
150
140
130
120
110
100
90
0
5
10
15
20
25
30
35
40
Time (min)
Exercise - MOPP II

Insert Figures 57 and 58 here

Subjective data comparison of test Garments 10 and 11 was achieved by means of a 2 x 3 (garment x administration) repeated measures analysis of variance on the SHI scores. While nearly all subjects were able to complete the first hour's walk for both conditions, the number of volunteers who were able to complete both walks was much smaller. In order to take advantage of the larger N during the first hour, a separate series of ANOVA's was performed on the first two administrations only. The results of these ANOVA's are graphically presented in Figures 59 and 60. The results indicate that when Garments 10 and 11 (VPFRU-CVC and CPU Control-CVC) were compared to one another, during the first hour's walk (N=9) the garments did not differ from one another. When results of the second walk were added into the analysis (N=4), the VPFRU-CVC showed less heat illness than the CPU Control-CVC during the second walk only. In both analyses, SHI scores increased significantly with each hour of walking in the heat.

Insert Figures 59 and 60 here

Figure 59

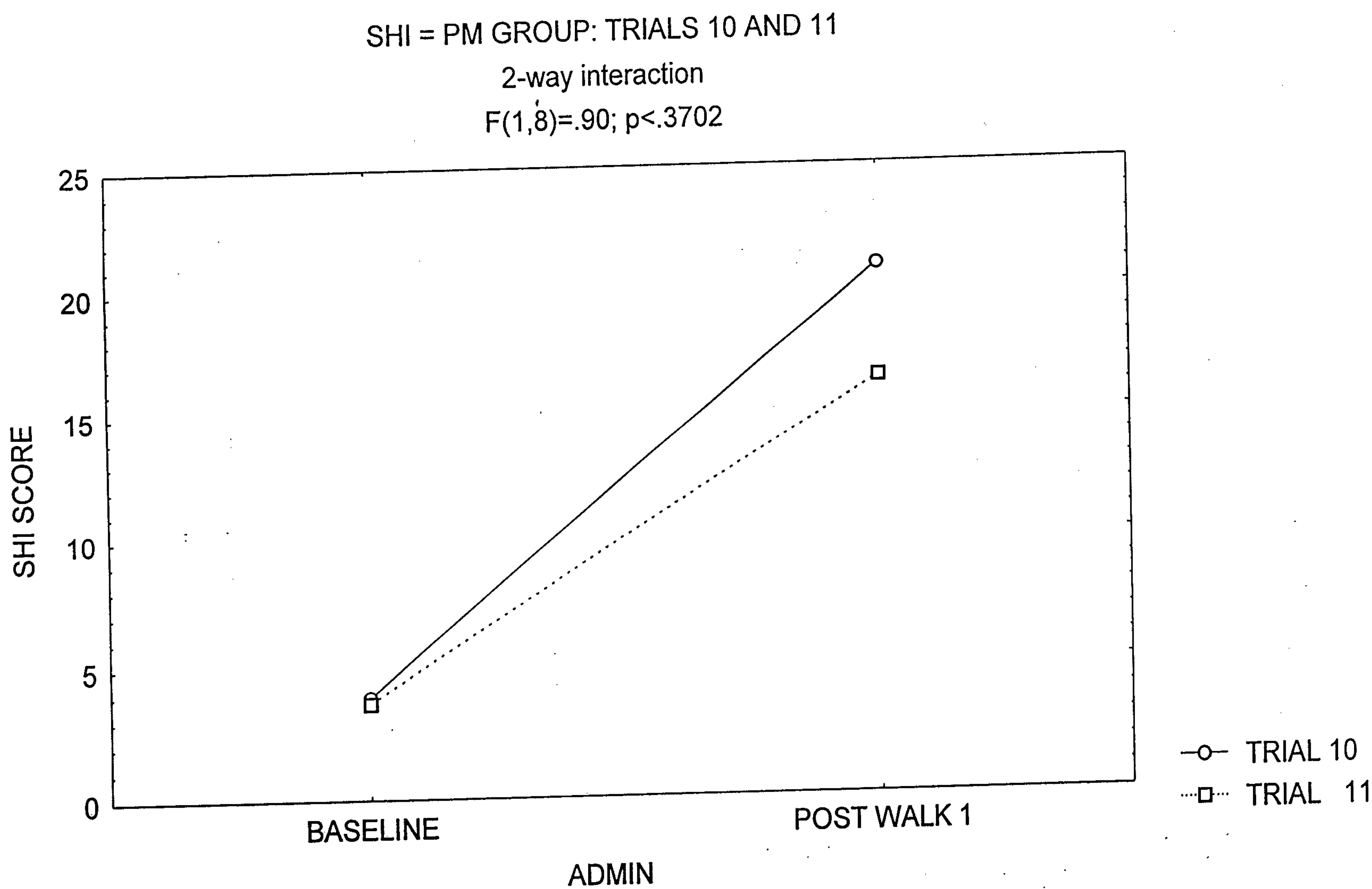
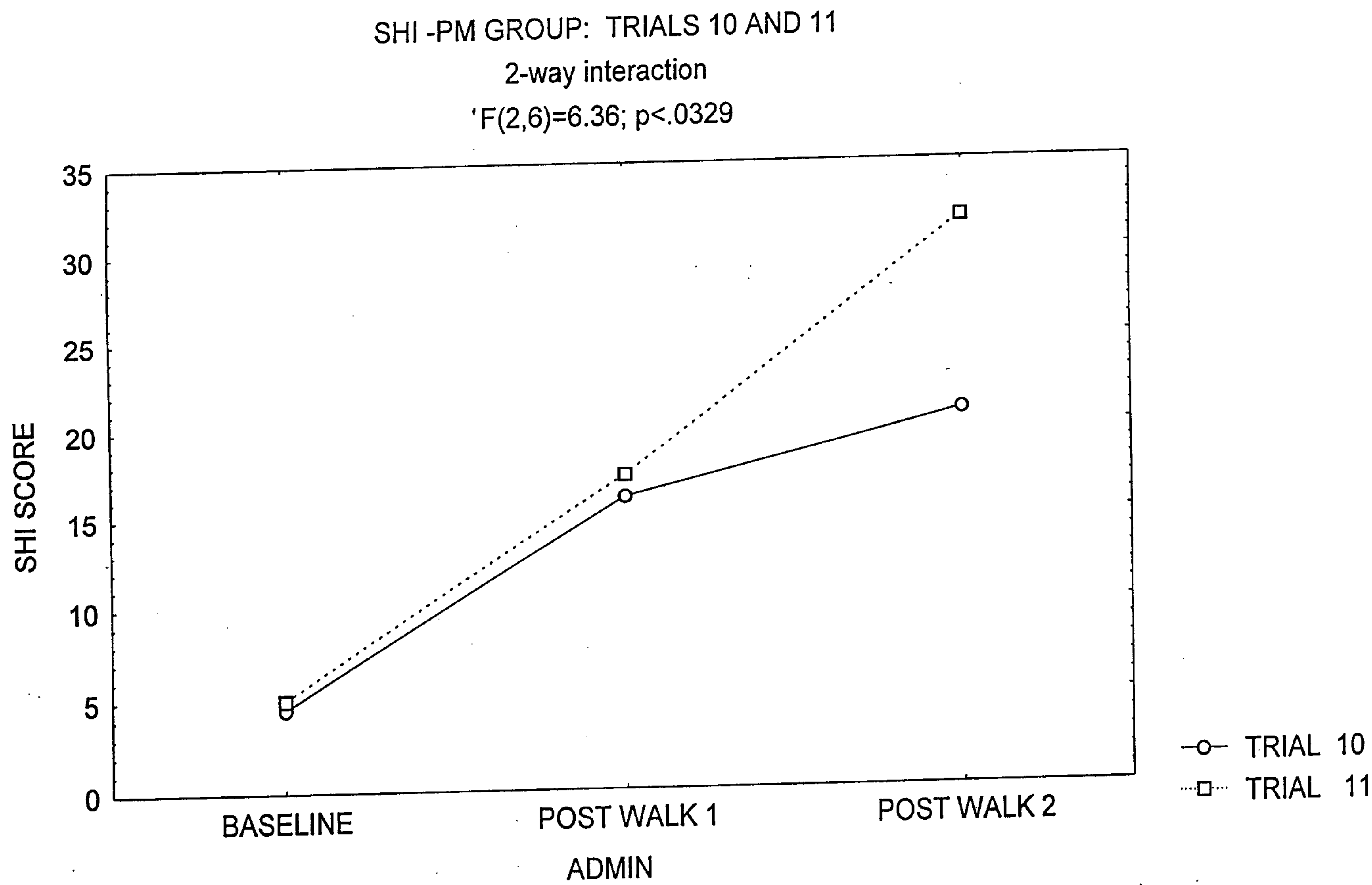

SHI = PM GROUP: TRIALS 10 AND 11
2-way interaction
F(1,8)=.90; p<.3702
25
20
15
10
5
0
SHI SCORE
BASELINE
POST WALK 1
ADMIN
TRIAL 10
TRIAL 11

Figure 60


SHI -PM GROUP: TRIALS 10 AND 11
2-way interaction
'F(2,6)=6.36; p<.0329
SHI SCORE
35
30
25
20
15
10
5
0
BASELINE
POST WALK 1
POST WALK 2
ADMIN
TRIAL 10
TRIAL 11

Garment Trials 12-13

Test times (Figure 56) for garment trials 12 and 13 (JSLIST AFR2 and BDO control) were not significantly different. T_{re}, ΔT_{re} (Figure 61), $\bar{T}_{sk}$, and HR (Figure 62) analyzed to 40 min (n=7, except n=6 for $\bar{T}_{sk}$) were also not significantly different at any of the 5-min intervals but each variable increased significantly over time in both trials.

Insert Figures 61 and 62 here

Figure 61

JSLIST YPG August 1995
ΔT_{re} Trials 12 & 13

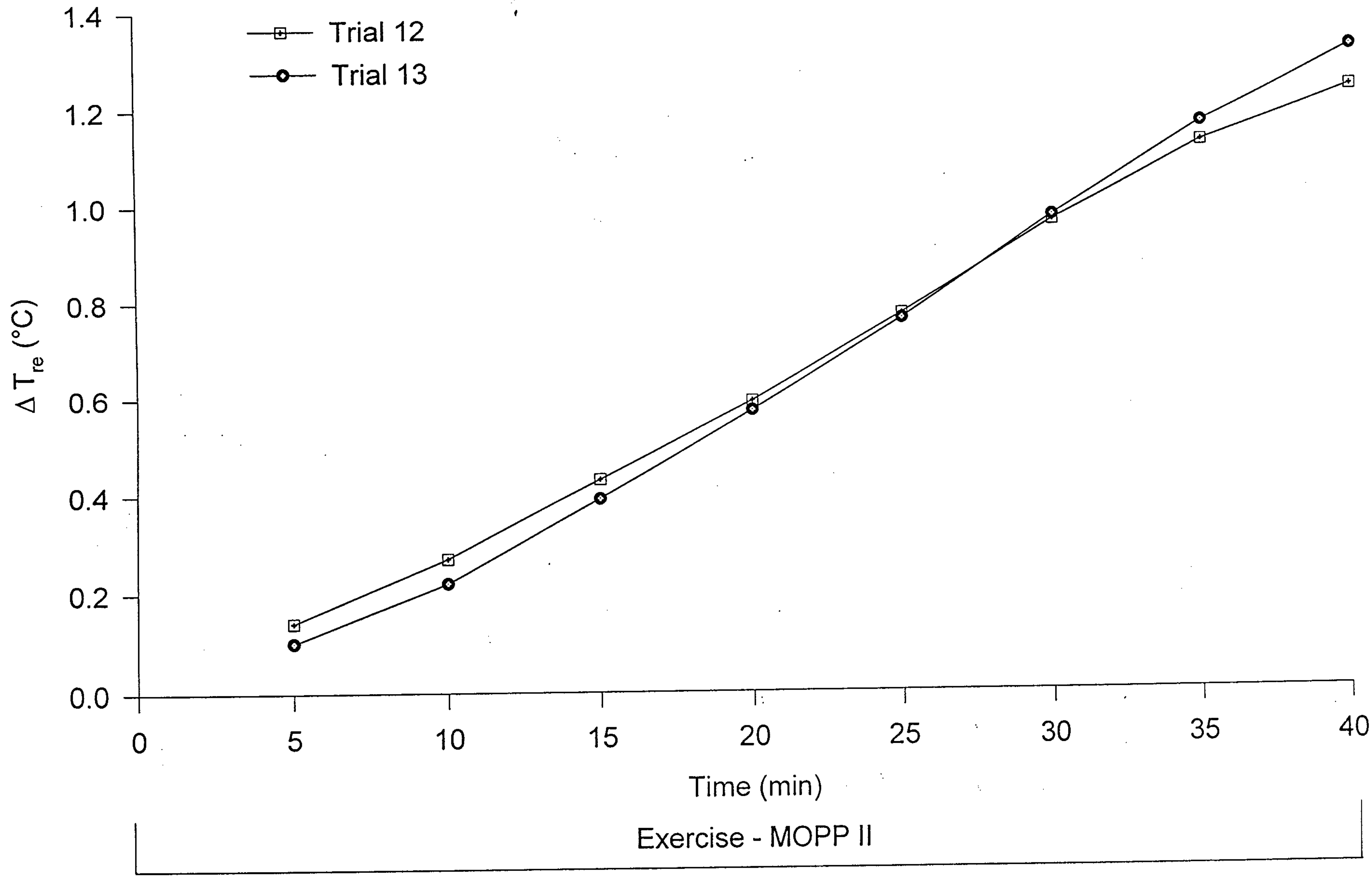
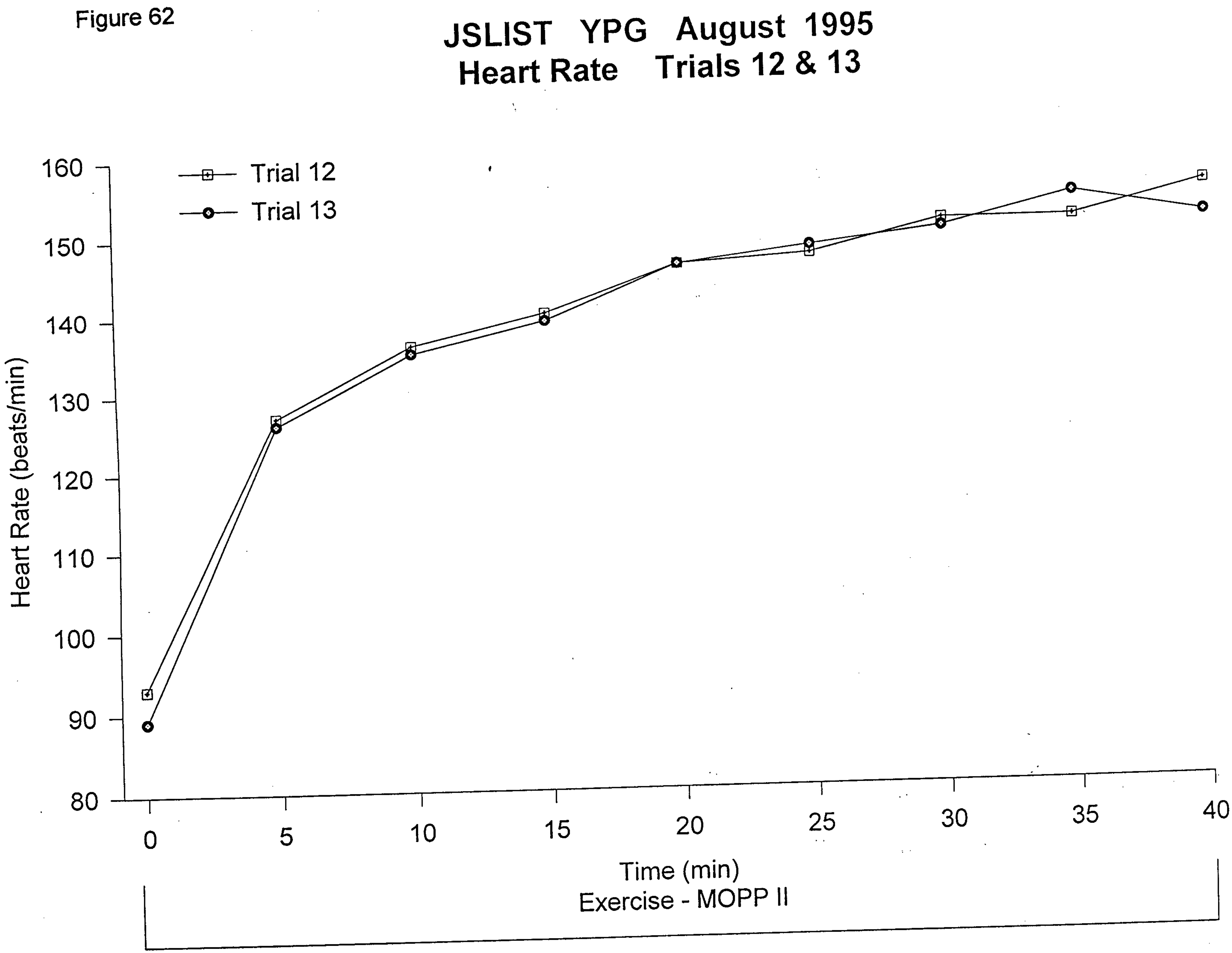


Figure 62



JSLIST YPG August 1995
Heart Rate Trials 12 & 13
Trial 12
Trial 13
Heart Rate (beats/min)
160
150
140
130
120
110
100
90
80
0
5
10
15
20
25
30
35
40
Time (min)
Exercise - MOPP II

Subjective data comparison of test garments 12 and 13 was achieved by means of a 2 x 3 (garment x administration) repeated measures analysis of variance on the SHI scores. While nearly all subjects were able to complete the first hour's walk for both conditions, the number of volunteers who were able to complete both walks was much smaller. In order to take advantage of the larger N during the first hour, a separate series of ANOVA's was performed on the first two administrations only. The results of these ANOVA's are presented in Figures 63 and 64. The results indicate that when Garments 12 and 13 (Aviator overgarment and BDO Control-AVC) were compared during the first hour's walk (N=9), the Aviator overgarment exhibited significantly less subjective heat illness than did the BDO Control-AVC. When results of the second walk were added into the analysis (N=4), there was no significant difference between the two garments. In both analyses, SHI scores increased significantly with each hour's walk in the heat.

Insert Figures 63 and 64 here

Figure 63

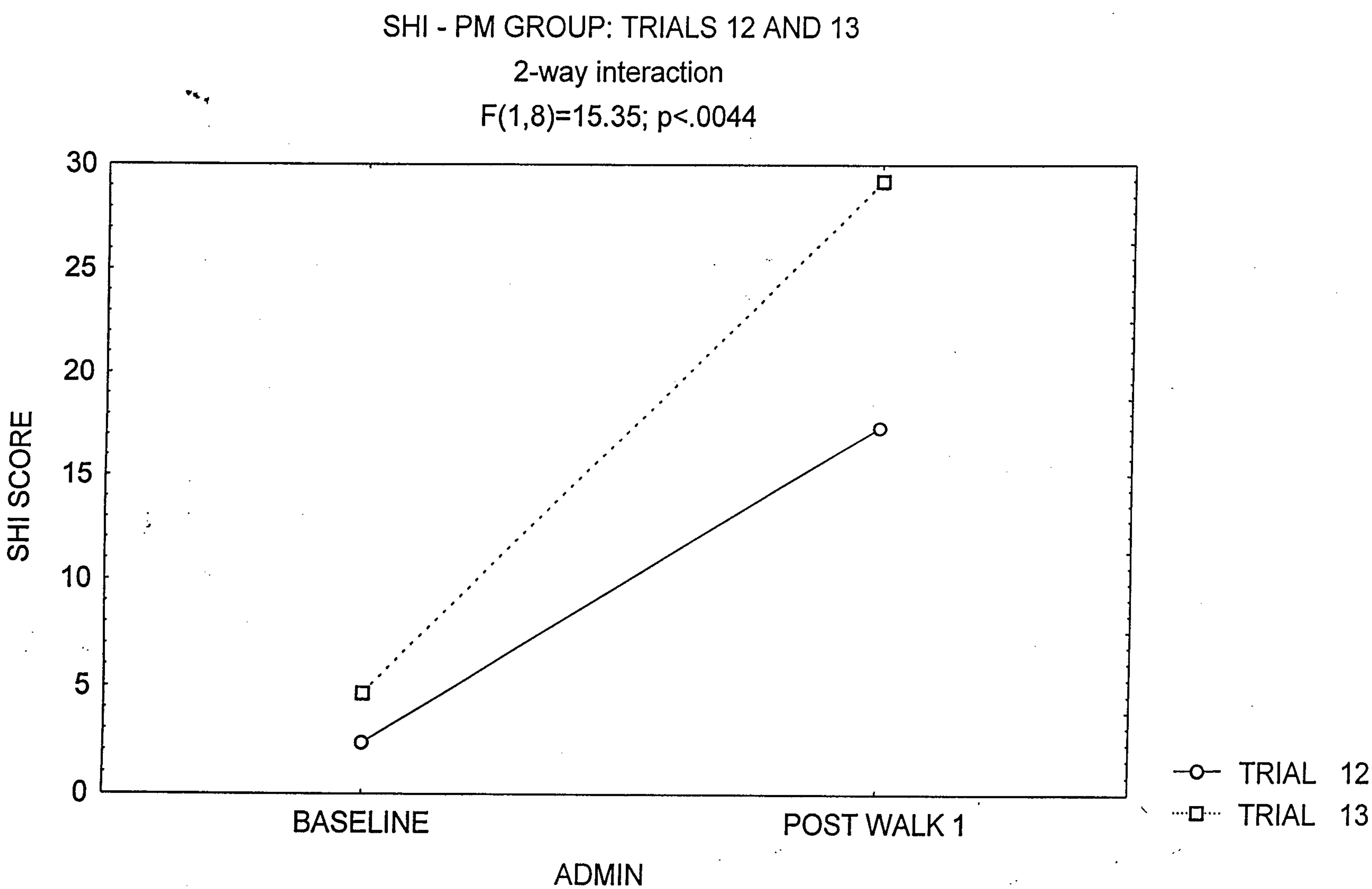

SHI - PM GROUP: TRIALS 12 AND 13
2-way interaction
F(1,8)=15.35; p<.0044
SHI SCORE
0
5
10
15
20
25
30
BASELINE
POST WALK 1
ADMIN
TRIAL 12
TRIAL 13

Figure 64

SHI - PM GROUP: TRIALS 12 AND 13
2-way interaction
$F(2,6)=.73; p<.5207$

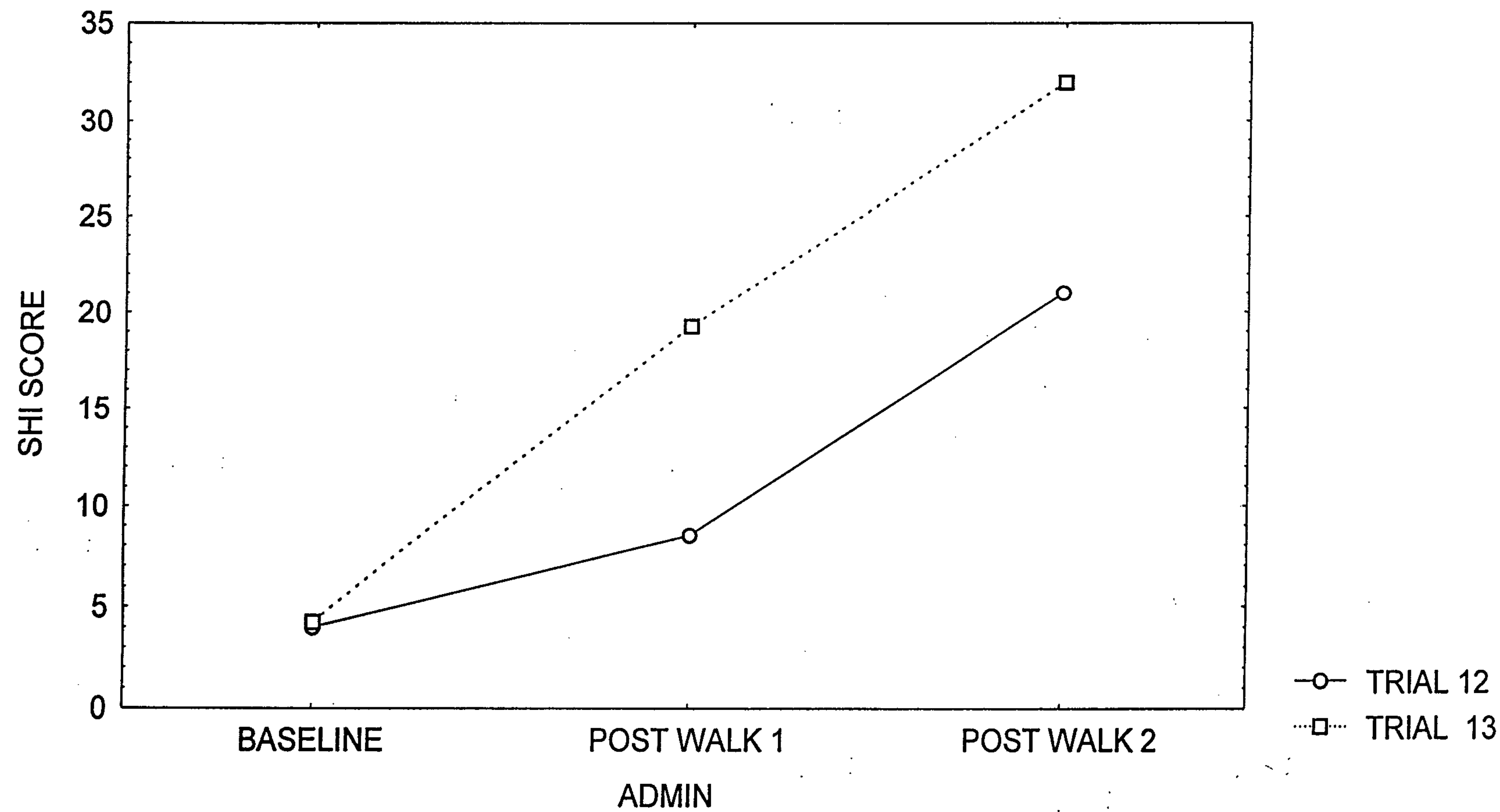


Table 6. TEST TIMES in the Field; T_{re} and HR at 60 min

Means (SD)

Group 1 (n=11[3]), Garment Trials 1-9

Group 2 (n=9), Garment Trials 10-13

GARMENT TRIALS	TEST TIME (min)	T_{re} at 60 min / n at 60 min	HR at 60 min / n at 60 min
1. OFR1 +	105 (19)	38.08 (0.41) /11	105 (11) / 11
2. OFR2 +	91 (23)	38.16 (0.54) /10	115 (23) / 10
3. ONFR1 +	97 (31) 95 (30)	37.99 (0.37) /10	103 (23) / 10
4. ONFR2 +	105 (16) 101 (21)	38.13 (0.38) /11	112 (18) / 11
5. ONFR3 +	95 (30)	37.99 (0.44) / 9	114 (25) / 9
6. SAR +	112 (12) 112 (12)	37.93 (0.28) /11	101 (18) / 11
7. BDO +	81 (24)	38.31 (0.36) / 9	110 (18) / 9
8. DNFR1 -	117 (6)	37.72 (0.41) /11	103 (13) / 11
9. SAR -	115 (15) 116 (14)	37.61 (0.26) /11	105 (17) / 11
10. VPFRU +	86 (41)	38.11 (0.53) / 6	120 (27) / 6
11. CPU +	68 (26)	38.18 (0.55) / 6	121 (27) / 6
12. AFR2 +	68 (30)	38.02 (0.46) / 5	116 (18) / 6*
13. BDO +	70 (38)	38.18 (0.27) / 5	126 (15) / 5

+ duty uniform worn with test uniform (TBDU trials 1-7, CVC trials 10-11, AVC trials 12-13)

- test uniform only

* For Trial 12: n=6 for HR includes ss14, 15, 16, 18, 19, 20... but n=5 for T_{re} because data after 50 min was not usable for s19.

[3] Group 1 began with 12 volunteers, but one did not complete testing due to an (unrelated) injury. Where available, means (SD) for n=12 are listed below those for n=11.

DISCUSSION

CHAMBER AND FIELD STUDIES

As part of the development and acquisition process for improved chemical protective clothing for soldiers, sailors, marines and airmen, the Joint Service Lightweight Integrated Suit Technology Program requested the heat strain evaluations described in this report. The primary purpose of these evaluations was to compare heat strain imposed by the JSLIST prototype protective garments with the currently fielded protective garments (controls). In the laboratory, tightly controlled experiments provided results enabling us to evaluate, compare and rank order the garments with respect to physiologic and subjective measures of heat strain. Results of the field study helped garment developers and military users determine if there were heat stress, comfort and wearability issues when the garments were worn in a somewhat realistic setting during military type activity. Based on these studies we would be able to answer the question: Does one or more of the prototype garments impose less heat strain than the currently fielded garments do? These experiments conform to recommended parameters for garment evaluation to support the Health Hazard Assessment process (U.S. Army Center for Health Performance and Preventive Medicine, 1996; Levine, Sawka, Gonzalez, 1995).

The garment trials were counterbalanced so that no garment would have preferential or detrimental weighting due to test order, or (in the field) variation in daily environmental conditions. Test subjects served as their own controls (each subject tested in each garment used in a particular comparison) to help minimize variation naturally occurring in a group of volunteers. Men and women were included as test subjects in a ratio of approximately 10:1 because the test garments are designed for use throughout the military services, where women represent approximately 10% of the forces. Data for the male and female volunteers was analyzed together because the time restraints of the program prevented large enough groups of each gender. The women's tests were not controlled for phase of menstrual cycle, also due to the time constraints of the program. The counterbalanced trials minimized the effect of variability in core temperature due to cycle phase. To minimize the possibility of changing ambient conditions (in the field) and changing physiological conditions (in the volunteers), testing was completed in as short a time span as was possible considering the numerous garment comparisons and the between-test rest needed for the

volunteers. In both studies comparison tests were conducted at the same time of day to control for circadian periodicity. In the chamber study, hydration status was controlled. In the field study, hydration status was monitored and fluid consumption was encouraged, fluids were provided both during and between tests, but no rigid schedule for fluid consumption was enforced. In both studies, recommendations were made (to both the subjects and to their NCOs and commanding officers) regarding control of the subjects' status with respect to diet (including food and fluids, alcohol and non-prescription medication), sleep and exercise, as these could affect measured test variables.

In the environmental chamber and in the field, the garment tests were grouped so that the prototypes and controls in several categories (overgarments, duty uniforms, undergarments) were compared. The chemical protective overgarment is used in most military operations where the protective clothing can be donned over the duty uniform in the event of a chemical threat. Both the CB duty uniform design and the CB overgarment design without a duty uniform under it were tested because the CB duty uniform design is considered for use in some service jobs, while the CB overgarment design without a standard duty uniform underneath is primarily considered if there is advance notice of a chemical threat during warm or hot weather. The CB undergarments were tested as they are used by armored crew members. In the chamber, two trials were tested at a temperate rather than a hot environment, in order to address a specific military requirement.

The most fundamental finding for all garment trials in both the chamber and the field studies in which the CB protective garment was worn as an overgarment with a duty uniform, (based on test time, rectal and skin temperatures, as well as subjective heat illness), was that the BDO control trial imposed the greatest heat stress, while the SAR, and CPO (the CPO was tested only in the chamber study) control trials imposed the least. Physiologic and subjective results indicate the JSLIST garments were generally not significantly different from one another, and ranged between the best and worst controls. In both the chamber and field studies, most cases of early withdrawal from a trial were voluntary (i.e. the subject requested withdrawal due to symptoms of exhaustion from heat strain such as headache, syncope, and feelings of breathlessness) rather than mandatory (due to having met pre-determined physiologic limits). Wearing chemical protective clothing, which causes uncompensable heat

stress, has been shown to lower the physiological strain a person can tolerate (Montain et al, 1994).

The chamber evaluation ranked the best and worst controls as respectively better and worse than the JSLIST garments. Within the range of the control garments, the JSLIST garments themselves did not consistently line up based on the variables measured in the current study. In the chamber, based on ΔT_{re}, $\bar{T}_{sk}$, and HR, the JSLIST garments were not significantly different from each other, ranging between the best (SAR, CPO) and worst (BDO) controls. Based on T_{re} only, garment OFR2 appeared to be less stressful (non-significant) than the other JSLIST garments. T_{re} and ΔT_{re} data indicate that (by 45 and 35 min, respectively), after the BDO, the JSLIST garment ONFR 3 was hottest. This is consistent with the thermal manikin evaluation which found ONFR3 ranked the worst of the JSLIST garments. Subjective analyses indicate garments OFR 2, BDO and ONFR 2 were perceived as most stressful, while the SAR was perceived as the least stressful. Except for OFR2, the JSLIST garments (OFR1, ONFR1, ONFR2, ONFR3) and the CPO were not perceived as different. In each of the JSLIST garment trials, only one subject was able to complete 110 min of testing, while in the BDO no subjects completed 110 min, and in both the SAR and the CPO, four subjects completed the 110-min trial.

Results from the field and chamber studies were in agreement regarding the SAR and BDO controls (CPO not tested in the field) as best and worst, respectively, compared to the JSLIST garments. However, the ranking of the JSLIST garments was inconsistent between chamber and field for both physiological and subjective data. There was a trend (sometimes significant), based on test time, T_{re}, ΔT_{re}, $\bar{T}_{sk}$ and HR, for the OFR2 garment to be next worst (after the BDO) in imposing heat stress. ONFR1, based on $\bar{T}_{sk}$, was coolest in our field test. Based on subjective data, OFR1 tended to be worst of the JSLIST garments. Only 3 of 12 subjects in OFR2 completed the 120 min field test, compared to 1 in the BDO, 5 in ONFR2, 6 in trials OFR1 and ONFR1, and 8 in the Saratoga. The ONFR1 garment had been selected as the "worst case" JSLIST garment used for the YPG tests (based on the guarded hot plate evaluation), but ranked next best after the CPO and SAR in the manikin tests. These inconsistencies, due to small (sometimes statistically significant) differences in the measured variables, may not be physiologically significant, especially for data from the field study.

As expected, in both the chamber and field studies, trials comparing the overgarment plus duty uniform, to either overgarment with no duty uniform or the CB garment designed as a duty uniform, resulted in greater heat strain in terms of physiological variables, test time and subjective symptoms of heat illness (ONFR3+duty uniform vs ONFR3-no duty uniform in the chamber, and ONFR1 vs DNFR1 and SAR+duty uniform vs SAR-no duty uniform in the field). We found no significant differences between the CB overgarment vs duty uniform designs, at hot or temperate conditions in the chamber or field (trials ONFR3-no duty uniform vs DNFR2 and DNFR2 vs BDO-no duty uniform in the chamber; DNFR1 vs SAR-no duty uniform in the field). The undergarment trials in which the CPU was compared to the JSLIST VPFRU were not significantly different in the chamber or in the field, but physiological and subjective data show a small (non-significant) advantage for the VPFRU. However, in the field, this analysis was done for the time subjects were still in MOPP 2 (<60 min, due to dropouts); the only difference between the garments is the hood which was not in use during the first 60 min.

During the controlled chamber study and the more realistic setting of the field study, there were no unexpected problems with the JSLIST garments. There were several sizing-related complaints from the volunteers, including: 1) there seemed to be too much fabric at the neck of the integral hoods of the JSLIST garments, causing some discomfort. 2) Some of the volunteers, who were comfortable in their own socks and combat boots, could not wear the prototype chemical protective socks which made their boots fit too tightly.

Overall, both the physiological and subjective data for the field study and for the chamber study, indicate the currently fielded Battledress Overgarment imposes (and is perceived to impose) significantly greater heat strain compared to all the other garments tested. Similarly, the Saratoga Overgarment and the Navy's Chemical Protective Overgarment, impose significantly less. The JSLIST garments fall between these better and worse garments, however rank ordering of these garments differ somewhat when results of the chamber and field, and physiological and subjective data are considered.

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APPENDIX A

Profile of Mood States (POMS) Questionnaire

Below is a list of words that describe feelings people have. Please read each one carefully. Then fill in ONE space under the answer to the right which best describes HOW YOU HAVE BEEN FEELING DURING THE PAST WEEK INCLUDING TODAY.

	not at all 0	a little 1	moder-ately 2	quite a bit 3	extremely 4
1. Friendly	[]	[]	[]	[]	[]
2. Tense	[]	[]	[]	[]	[]
3. Angry	[]	[]	[]	[]	[]
4. Worn out	[]	[]	[]	[]	[]
5. Unhappy	[]	[]	[]	[]	[]
6. Clear-headed	[]	[]	[]	[]	[]
7. Lively	[]	[]	[]	[]	[]
8. Confused	[]	[]	[]	[]	[]
9. Sorry for things done	[]	[]	[]	[]	[]
10. Shaky	[]	[]	[]	[]	[]
11. Listless	[]	[]	[]	[]	[]
12. Peeved	[]	[]	[]	[]	[]
13. Considerate	[]	[]	[]	[]	[]
14. Sad	[]	[]	[]	[]	[]
15. Active	[]	[]	[]	[]	[]
16. On edge	[]	[]	[]	[]	[]
17. Grouchy	[]	[]	[]	[]	[]
18. Blue	[]	[]	[]	[]	[]
19. Energetic	[]	[]	[]	[]	[]
20. Panicky	[]	[]	[]	[]	[]
21. Hopeless	[]	[]	[]	[]	[]
22. Relaxed	[]	[]	[]	[]	[]
23. Unworthy	[]	[]	[]	[]	[]
24. Spiteful	[]	[]	[]	[]	[]
25. Sympathetic	[]	[]	[]	[]	[]
26. Uneasy	[]	[]	[]	[]	[]
27. Restless	[]	[]	[]	[]	[]
28. Unable to concentrate	[]	[]	[]	[]	[]
29. Fatigued	[]	[]	[]	[]	[]
30. Helpful	[]	[]	[]	[]	[]
31. Annoyed	[]	[]	[]	[]	[]
32. Discouraged	[]	[]	[]	[]	[]

Profile of Mood States (POMS) (continued)

	not at all 0	a little 1	moder-ately 2	quite a bit 3	extremely 4
33. Resentful	[]	[]	[]	[]	[]
34. Nervous	[]	[]	[]	[]	[]
35. Lonely	[]	[]	[]	[]	[]
36. Miserable	[]	[]	[]	[]	[]
37. Muddled	[]	[]	[]	[]	[]
38. Cheerful	[]	[]	[]	[]	[]
39. Bitter	[]	[]	[]	[]	[]
40. Exhausted	[]	[]	[]	[]	[]
41. Anxious	[]	[]	[]	[]	[]
42. Ready to fight	[]	[]	[]	[]	[]
43. Good natured	[]	[]	[]	[]	[]
44. Gloomy	[]	[]	[]	[]	[]
45. Desperate	[]	[]	[]	[]	[]
46. Sluggish	[]	[]	[]	[]	[]
47. Rebellious	[]	[]	[]	[]	[]
48. Helpless	[]	[]	[]	[]	[]
49. Weary	[]	[]	[]	[]	[]
50. Bewildered	[]	[]	[]	[]	[]
51. Alert	[]	[]	[]	[]	[]
52. Deceived	[]	[]	[]	[]	[]
53. Furious	[]	[]	[]	[]	[]
54. Efficient	[]	[]	[]	[]	[]
55. Trusting	[]	[]	[]	[]	[]
56. Full of pep	[]	[]	[]	[]	[]
57. Bad-tempered	[]	[]	[]	[]	[]
58. Worthless	[]	[]	[]	[]	[]
59. Forgetful	[]	[]	[]	[]	[]
60. Carefree	[]	[]	[]	[]	[]
61. Terrified	[]	[]	[]	[]	[]
62. Guilty	[]	[]	[]	[]	[]
63. Vigorous	[]	[]	[]	[]	[]
64. Uncertain about things	[]	[]	[]	[]	[]
65. Bushed	[]	[]	[]	[]	[]

Self-Report Questionnaire (Dishman SMI)

Read each of the following statements and write by each item the letter of the alternative which best describes how characteristic the statement is when applied to you. The alternatives are:

(a) extremely uncharacteristic of me

(b) somewhat uncharacteristic of me

(c) neither characteristic nor uncharacteristic of me

(d) somewhat characteristic of me

(e) extremely characteristic of me

Please be sure to answer every item and try to be as honest and accurate as possible in your responses. Your answers will be kept in the strictest confidence.

___ 1. I'm not very good at committing myself to do things.

___ 2. Whenever I get bored with projects I start, I drop them to do something else.

___ 3. I can persevere at stressful tasks, even when they are physically tiring or painful.

___ 4. If something gets to be too much of an effort to do, I'm likely to just forget it.

___ 5. I'm really concerned about developing and maintaining self-discipline.

___ 6. I'm good at keeping promises, especially the ones I make to myself.

___ 7. I don't work any harder than I have to.

___ 8. I seldom work to my full capacity.

___ 9. I'm just not the goal-setting type.

___ 10. When I take on a difficult job, I make a point of sticking with it until it's completed.

___ 11. I'm willing to work for things I want as long as it's not a big hassle for me.

___ 12. I have a lot of self-motivation.

___ 13. I'm good at making decisions and standing by them.

___ 14. I generally take the path of least resistance.

___ 15. I get discouraged easily.

___ 16. If I tell somebody I'll do something, you can depend on it being done.

Be sure to complete the items on the other side.

Self-Report Questionnaire (Dishman SMI) - continued

___ 17. I don't like to overextend myself.

___ 18. I'm basically lazy.

___ 19. I have a very hard-driving, aggressive personality.

___ 20. I work harder than most of my friends.

___ 21. I can persist in spite of pain or discomfort.

___ 22. I like to set goals and work toward them.

___ 23. Sometimes I push myself harder than I should.

___ 24. I tend to be overly apathetic.

___ 25. I seldom, if ever, let myself down.

___ 26. I'm not very reliable.

___ 27. I like to take on jobs that challenge me.

___ 28. I change my mind about things quite easily.

___ 29. I have a lot of willpower.

___ 30. I'm not likely to put myself out if I don't have to.

___ 31. Things just don't matter much to me.

___ 32. I avoid stressful situations.

___ 33. I often work to the point of exhaustion.

___ 34. I don't impose much structure on my activities.

___ 35. I never force myself to do things I don't feel like doing.

___ 36. It takes a lot to get me going.

___ 37. Whenever I reach a goal, I set a higher one.

___ 38. I can persist in spite of failure.

___ 39. I have a strong desire to achieve.

___ 40. I don't have much self discipline.

Subjective Heat Illness (SHI) Questionnaire

Subjective Heat Illness (SHI) Questionnaire

Circle the number of each item to correspond to
HOW YOU HAVE BEEN FEELING DURING THE TEST SESSION TODAY.
PLEASE ANSWER EVERY ITEM. If you did not have the symptom, circle zero (NOT AT ALL).

	not at all	slight	some-what	moder-ate	quite a bit	extreme
1. I felt lightheaded . . .	0	1	2	3	4	5
2. I had a headache . . .	0	1	2	3	4	5
3. I felt dizzy	0	1	2	3	4	5
4. I felt faint	0	1	2	3	4	5
5. My coordination was off . .	0	1	2	3	4	5
6. I was short of breath . .	0	1	2	3	4	5
7. It was hard to breathe . .	0	1	2	3	4	5
8. My heart was beating fast . .	0	1	2	3	4	5
9. I had a muscle cramp . .	0	1	2	3	4	5
10. I had stomach cramps . .	0	1	2	3	4	5
11. I felt weak	0	1	2	3	4	5
12. I felt constipated . . .	0	1	2	3	4	5
13. I felt warm	0	1	2	3	4	5
14. I was sweating all over . .	0	1	2	3	4	5
15. Parts of my body felt numb. .	0	1	2	3	4	5
16. My vision was blurry . .	0	1	2	3	4	5
17. I lost my appetite . . .	0	1	2	3	4	5
18. I felt sick	0	1	2	3	4	5
19. I felt irritable . . .	0	1	2	3	4	5
20. I was thirsty	0	1	2	3	4	5
21. I felt tired	0	1	2	3	4	5
22. I felt restless . . .	0	1	2	3	4	5

APPENDIX B

STATISTICAL COMPARISONS of Physiological Data (Chamber)

Statistical significance is accepted at the p<0.05 level of confidence; p<0.05 is assumed except where noted otherwise. When the symbol for greater than (>) or less than (<) is used to describe differences in the data, statistical significance is indicated. Non-Significance is indicated as NS. (When significance is not specified, NS is assumed.)

Garment Trials 1-2-3-4-5-6-7-8 (and 9)

<u>Test Time</u> Garment Trials 1-9, anova (n=12), Figure 2: 6, 8 > 1, 2, 7 (p<0.05).

<u>Rectal Temperature</u>

Garment Trials 1-8, anova to 40 min (n=12), Figure 3a.

at 5 min 8, 5 > 1, 2
at 10 min 8, 5 > 7, 1, 6, 2 and 8, 5, 4 > 2
at 15 min 8, 5 > 7, 1, 6, 2 and 8, 5, 4 > 2
at 20 min 8, 5 > 6, 2
at 25 min 5, 8 > 6, 2
at 30 min 5 > 7, 6, 2 and 5, 4, 8, 1, 3 > 2 and 5, 4, 8 > 6, 2
at 35 min 5, 4 > 2, 6 and 5, 4, 7, 3, 8, 1 > 6
at 40 min 5 > 3, 1, 8, 2, 6 and 5, 7, 4, 3, 1, 8, 2 > 6

Garment Trials 1-8, anova to 50 min (n=10), Figure 3b.

at 5 min 4, 8 > 2
at 10 min 8 > 2
at 15 min 4 > 2
at 20 min 4, 8 > 6, 2 and 4, 8, 5 > 2
at 25 min 4, 5, 8 > 2
at 30 min 5, 4, 7, 8 > 2
at 35 min 5, 4 > 6, 2 and 5, 4, 7 > 2
at 40 min 5 > 2, 6 and 5, 7 > 6
at 45 min 7, 5 > 2, 8, 6 and 7, 5, 4 > 6
at 50 min 7, 5, 4 > 8, 6 and 7, 5 > 3, 2, 8, 6 and 7 > 1, 3, 2, 8, 6

analysis of Garment Trials 1-2-3-4-5-6 only, anova to 40 min (n=12), no figure.

at 5 min NS
at 10 min 5 > 1, 6, 2 and 5, 4 > 2
at 15 min 5, 4 > 6, 2
at 20 min 5 > 6, 2
at 25 min 5, 4 > 6, 2

at 30 min 5, 4, 1 > 6, 2
at 35 min 5 > 1, 2, 6 and 5, 4, 3, 1 > 6
at 40 min 5> 3, 1, 2, 6 and 5, 4, 3, 1 > 6

analysis of Garment Trials 1-2-3-4-5-6 only, anova to 50 min (n=10), no figure.
at 5 min 4 > 1, 2 and 4, 5 > 2
at 10 min 4, 5 > 2
at 15 min 4 > 1, 2 and 4, 5, 3 > 2
at 20 min 4, 5, 3 > 2
at 25 min 4, 5, 3 > 2
at 30 min 5, 4 > 6, 2 and 3 > 2
at 35 min 5, 4 > 6, 2
at 40 min 5 > 2, 6
at 45 min 5 > 2, 6 and 5, 4 > 6
at 50 min 5, 4 > 6

analysis of Garment Trials 1-2-3-4-5-7 only, anova to 40 min (n=12), no figure.
at 5 min 5, 4 > 1, 2
at 10 min 5 > 7, 1, 2 and 5, 4 > 2
at 15 min 5, 4 > 2 and 5 > 1, 2
at 20 min 5, 4 > 7, 2 and 5, 4, 3 > 2
at 25 min 5, 4, 3 > 2
at 30 min 5 > 7, 2 and 5, 4, 1, 3 > 2
at 35 min 5, 4 > 2
at 40 min 5 > 3, 1, 2

analysis of Garment Trials 1-2-3-4-5-7 only, anova to 50 min (n=10), no figure.
at 5 min 4, 5 > 2
at 10 min 4, 5 > 2
at 15 min 4, 5 > 2
at 20 min 4, 5 > 2
at 25 min 4, 5 > 2
at 30 min 5, 4, 7 > 2
at 35 min 5, 4, 7 > 2
at 40 min 5, 7 > 2
at 45 min 7, 5 > 2
at 50 min 7 > 1, 3, 2 and 7, 5 > 3, 2

analysis of Garment Trials 1-2-3-4-5-8 only, anova to 40 min (n=12), no figure.
at 5 min 8, 5, 4 > 1, 2
at 10 min 8, 5 > 1, 2
at 15 min 8, 5 > 1, 2 and 8, 5, 4 > 2
at 20 min 8 > 1, 2 and 8, 5, 4, 3 > 2
at 25 min 5 > 2

at 30 min 5, 8, 4, 1, 3 > 2
at 35 min 5 > 1, 2 and 5, 4 > 2
at 40 min 5 > 3, 1, 8, 2

analysis of Garment Trials 1-2-3-4-5-8 only, anova to 50 min (n=10), no figure.
at 5 min 4, 8, 5 > 2
at 10 min 8, 4, 5 > 2
at 15 min 4, 8, 5 > 2
at 20 min 4, 8, 5 > 2
at 25 min 4, 5, 8 > 2
at 30 min 5, 4, 8 > 2
at 35 min 5 > 2
at 40 min 5 > 2
at 45 min 5 > 2, 8
at 50 min 5, 4 > 8

<u>Change in Rectal Temperature</u> (for each 5-min value minus the value at 10 min)
Garment Trials 1-8, anova to 40 min (n=12), Figure 4a.
15 - 25 min NS
at 30 min 1> 2, 6, 8
at 35 min 7, 1, 5 > 6, 8
at 40 min 7 > 4, 6, 8 and 7, 5, 1, 2 > 6, 8 and 7, 5, 1, 2, 3, 4 > 8

Garment Trials 1-8, anova to 50 min (n=10), Figure 4b.
15 - 30 min NS
at 35 min 7, 1, 5 > 8
at 40 min 7 > 3, 6, 8 and 7, 5, 2, 1 > 8
at 45 min 7 > 4, 3, 6, 8 and 7, 2, 5 > 6, 8 and 7, 2, 5, 1, 4, 3 > 8
at 50 min 7 > 5, 1, 2, 4, 3, 6, 8 and 7, 5, 1, 2 > 6, 8 and 7, 5, 1, 2, 4, 3 > 8

analysis of Garment Trials 1-2-3-4-5-6 only, anova to 40 min (n=12), no figure.
15 - 25 min NS
at 30 min 1 > 6
at 35 min 1, 5 > 6
at 40 min 5, 1, 2 > 6

analysis of Garment Trials 1-2-3-4-5-6 only, anova to 50 min (n=10), no figure.
15 - 40 min NS
at 45 min 2, 5 > 6
at 50 min 5, 1, 2 > 6

analysis of Garment Trials 1-2-3-4-5-7 only, anova to 40 min (n=12), no figure.
15 - 25 min NS
at 30 min 1 > 2

at 35 min NS
at 40 min 7 > 4

analysis of Garment Trials 1-2-3-4-5-7 only, anova to 50 min (n=10), no figure.
15 - 35 min NS
at 40 min 7 > 3
at 45 min 7 > 4, 3
at 50 min 7 > 5, 1, 2. 4, 3

analysis of Garment Trials 1-2-3-4-5-8 only, anova to 40 min (n=12), no figure.
15 - 25 min NS
at 30 min 1 > 8
at 35 min 1, 5, 3 > 8
at 40 min 5, 1, 2, 3, 4 > 8

analysis of Garment Trials 1-2-3-4-5-8 only, anova to 50 min (n=10), no figure.
15 - 35 min NS
at 40 min 5, 2, 1 > 8
at 45 min 2, 5, 1, 4, 3 > 8
at 50 min 5, 1, 2, 4, 3 > 8

<u>Mean Weighted Skin Temperature</u>
Garment Trials 1-8, anova to 40 min (n=12), Figure 5a.
5 - 30 min 7 > 6
at 35 min 7 > 8, 6
at 40 min 7 > 8,6

Garment Trials 1-8, anova to 50 min (n=10), Figure 5b.
at 5 min 7 > 3, 6
at 10 min 7 > 3, 6
at 15 min 7 > 6
at 20 min 7 > 6
at 25 min 7 > 6
at 30 min NS
at 35 min 7 > 6
at 40 min 7 > 8, 6
at 45 min 7 > 8, 6
at 50 min 7 > 8, 6

<u>Heart Rate</u>
Garment Trials 1-8, anova to 40 min (n=12), Figure 6a.
5 min NS
at 10 min 8 > 3, 6
at 15 min NS

at 20 min 5, 2 > 6
at 25 min 2, 1 > 6
at 30 min 3, 1, 5 > 6
at 35 min NS
at 40 min 5 > 6, 8

Garment Trials 1-8, anova to 50 min (n=10), Figure 6b.
at 5 min 8 > 2
at 10 min 8 > 6, 3
at 15 min NS
at 20 min NS
at 25 min 2, 1 > 6
at 30 min 1 > 6
at 35 min NS
at 40 min NS
at 45 min NS
at 50 min 5 > 8

Sweating Rate, Evaporated Sweat, and Evaporative Heat Loss: Garment Trials 1-9, anova (n=12), Figures 7 and 8.
SR: Not Significant (p=0.58)
% Evaporated: Not Significant (p=0.24)
Heat Loss: Not Significant (p=0.71)

Garment Trials 5 and 9

Test Time: (Figure 2) 9 > 5 (p<0.01)

Rectal Temperature
anova to 50 min (n=11), Figure 9a.
5-50 min 5 > 9

anova to 80 min (n = 6), Figure 9b.
at 5 min NS
10 - 80 min 5 > 9

Change in Rectal Temperature
anova to 50 min (n=11), Figure 10a.
15 - 25 min NS
30 - 50 min 5 > 9

anova to 80 min (n=6), Figure 10b.
15 - 45 min NS

50 - 80 min 5 > 9

Mean Weighted Skin Temperature

anova to 50 min (n=11), Figure 11a.

5 - 20 min NS

25 - 50 min 5 > 9

anova to 80 min (n= 6), Figure 11b.

5 - 10 min 5 > 9

15 - 30 min NS

40 - 80 min 5 > 9

Heart Rate

anova to 50 min (n=11), Figure 12a.

5 - 35 min NS

40 - 50 min 5 > 9

anova to 65 min (n=9), no figure.

5 - 35 min NS

40 - 65 min 5 > 9

anova to 80 min (n=6), Figure 12b.

5 - 45 min NS

50 - 80 min 5 > 9

Sweating Rate, Evaporated Sweat, and Evaporative Heat Loss (n=12) Figures 7 and 8.

SR: 9 < 5 (<0.01)

% Evap: 9 > 5 (p<0.05)

Heat Loss: Not Significant (p=0.15)

Garment Trials 9 and 12

Test Time: (Figure 13) Not Significant (p=0.19)

Rectal Temperature

anova to 50 min (n=10), Figure 14a.

5 - 20 min 9 > 12

25 - 50 min NS

anova to 80 min (n=8), Figure 14b.

5 - 80 min NS

Change in Rectal Temperature

anova to 50 min (n=10), Figure 15a.
15 - 20 min NS
25 - 50 min 12 > 9

anova to 80 min (n=8), Figure 15b.
15 - 80 min (except min 55) NS
at 55 min 12 > 9

Mean Weighted Skin Temperature
anova to 50 min (n=10), Figure 16a.
at 5 min 12 > 9
10 - 50 min NS

anova to 80 min (n=8), Figure 16b.
at 5 min 12 > 9
10 - 80 min NS

Heart Rate
anova to 50 min (n=10), Figure 17a.
5 - 50 min NS

anova to 80 min (n=8), Figure 17b.
5 - 80 min NS

Sweating Rate, Evaporated Sweat, and Evaporative Heat Loss: (Figures 18 and 19)
SR: Not Significant (p=0.44)
% Evap: Not Significant (p=0.93)
Heat Loss: Not Significant (p= 0.79)

Garment Trials 10 and 11

Test Time: (Figure 20) Not Significant (p=0.15)

Rectal Temperature
anova to 60 min (n=11), Figure 21a.
5 - 30 min NS
35 - 60 min 11 > 10

anova to 90 min (n=6), Figure 21b.
5 - 40 min NS
45 - 90 min 11 > 10

Change in Rectal Temperature

anova to 60 min (n=11), Figure 22a.
15 - 45 min NS
50 - 60 min 11 > 10

anova to 90 min (n=6), Figure 22b.
15 - 70 min NS
75 - 90 min 11 > 10

Mean Weighted Skin Temperature
anova to 60 min (n=11), Figure 23a.
5 - 60 min NS

anova to 90 min (n=6), Figure 23b.
5 - 90 min (except min 80) NS
at 80 min 11 > 10

Heart Rate
anova to 60 min (n=11) Figure 24.
5 - 45 min NS
50 - 60 min 11 > 10

anova to 90 min (n=6) no figure.
5 - 75 min NS
80 - 85 min 11 > 10
at 90 min NS

Sweating Rate, Evaporated Sweat, and Evaporative Heat Loss: (Figures 25 and 26)
SR: Not Significant (p=0.79)
% Evap: Not Significant (p=0.31)
Heat Loss: Not Significant (p=0.15)

Garment Trials 12 and 13

Test Time: (Figure 13) 12<13 (p<0.05)

Rectal Temperature
anova to 65 min (n=10), Figure 27.
5 - 25 min 13 > 12
30 - 45 min NS
50 - 65 min 12 > 13

anova to 75 min (n=8) no figure.
5 - 30 min 13 > 12

35 - 45 min NS
50 - 75 min 12 > 13

Change in Rectal Temperature, Figure 28a.
anova to 65 min (n=10)
15 - 30 min NS
35 - 65 min 12 > 13

anova to 75 min (n=8), Figure 28b.
15 - 35 min NS
40 - 75 min 12 > 13

Mean Weighted Skin Temperature
anova to 65 min (p=65), Figure 29.
5 - 65 min 12 > 13

anova to 75 min (n=8) no figure.
5 - 75 min 12 > 13

Heart Rate
anova to 65 min (n=10), Figure 30a.
5 - 25 min NS
30 - 65 min 12 > 13

anova to 75 min (n=8), Figure 30b.
5 - 30 min NS
35 - 75 min 12 > 13

Sweating Rate, Evaporated Sweat, and Evaporative Heat Loss: (Figures 18 and 19)
SR: 12>13 ($p<0.01$)
% Evap: 12<13 ($p<0.01$)
Heat Loss: 12>13 ($p<0.01$)

Garment Trials 13 and 14

Test Time: (Figure 13) Not Significant ($p=0.34$)

Rectal Temperature
anova to 55 min (n=11), Figure 31a.
5 - 55 min NS

anova to 75 min (n=9), Figure 31b.
5 - 75 min NS

Change in Rectal Temperature
anova to 55 min (n=11), Figure 32a.
5 - 55 min NS

anova to 75 min (n=9), Figure 32b.
5 - 75 min NS

Mean Weighted Skin Temperature
anova to 55 min (n=11), Figure 33.
5 - 10 min NS
14 - 35 min 14 > 13
40 - 55 min NS

anova to 75 min (n=9) no figure.
5 - 75 (except min 30) NS
at 30 min 14 > 13

Heart Rate
anova to 55 min (n=9), Figure 34a.
5 - 55 min NS

anova to 75 min (n=9), Figure 34b.
5 - 75 min NS

Sweating Rate, Evaporated Sweat, and Evaporative Heat Loss: (Figures 18 and 19)
SR: Not Significant (p=0.87)
% Evap: Not Significant (p=0.10)
Heat Loss: 13>14 (p<0.01)

APPENDIX C

STATISTICAL COMPARISONS of Physiological Data (Field)

Garment Trials 1-2-3-4-5-6-7-8-9

Mean Test Time per Trial, Garment Trials 1-9 (n=11) Figure 45.

Test time for Trials 8,9,6 > 7 ($p<0.01$). (same results when trials 1-7 and 8,9 are analyzed separately)

ΔT_{re} Garment Trials 1-9, to 50 min, n=9 (Value at each 5-min interval minus value at zero min , stats on actual rectal temperature values show similar trends.) Figure 46.

Trials 1-9 STATS ($p<0.01$) n=9

@ min 50 trials 7 > 5,1,3,6 > 9,8
also trials 2,4 > 3 > 9,8

@ min 45 trials 7 > 1,3,6 > 8,9
also trials 2,5,4 > 6 > 8,9

@ min 40 trials 7 > 6 > 8,9
also trials 2,4,5,1 > 6 > 8,9 (also 3 > 8,9)

@ min 35 trials 7,2,4,5,1,3,6 > 9,8

@ min 30 trials 4,2,7 > 9,8 (differences before 30 min are non-significant)

Mean weighted skin temperature Garment Trials 1-9, n=7 (no figure). Within each 5-min time, garment trials are listed from hottest to coolest skin temperatures.

@ min 50 trials 5, 7, 2, 4, 1 > 3, 8, 9 (6 is NS)
@ min 45 trials 4, 7, 2, 5, 6, 1 > 8, 9 (3, 8, 9 NS)
@ min 40 trials 7, 1, 2, 4 > 3, 8, 9 (also 6, 5 > 9)
@ min 35 trials 7, 4, 2 > 3, 8, 9 (also 1 > 8, 9) (6 and 5 NS)
@ min 30 trials 7, 2 > 3, 9, 8 (also 4, 1 > 9, 8) (6 and 5 NS)
@ min 25 trials 7, 2 > 9 (4, 1, 5, 6, 8, 3, 9 NS)
@ min 20 trial 7 > 9 (2, 4, 1, 5, 6, 8, 3 NS)
@ min 15 trial 2 > 9 (7, 1, 8, 4, 5, 6, 3 NS)

Heart Rate, Garment Trials 1-9 (to 50 min) Figure 47.

Trials 1-9 STATS ($p<0.01$) n=9

@ min 50 and min 45 NS (subjects were resting)

@ min 40 trials 7,2 > 9,8

also trials 4,1 > 9,8

@ min 35 trials 2,7,4 > 9,8

@ min 30 trials 7,2,4 > 9,8

@ min 25 trials 7,2 > 8

@ min 20 trials 4 > 8

ΔT_{re}, Garment Trials 3,6,8,9 (to 50 min) Figure 48.

see Stats for trials 1-9

Heart Rate, Garment Trials 3,6,8,9 (to 50 min) Figure 49.

see Stats for trials 1-9

Mean Test Time per Trial, Garment Trials 10,11 (n=9) and 12,13 (n-9) Figure 50.

Test times for Trials 10-11 NS ($p=0.1935$)

Test times for Trials 12-13 NS ($p=0.8399$)

ΔT_{re}, Garment Trials 10,11 (to 40 min, n=7) Figure 51.

Trial x Time highly NS ($p=0.9988$)

ΔT_{re}, Garment Trials 10, 11 (to 70 n=4, 80 n=3 min) no figure.

Trial x Time NS ($p=$ 0.0975, 0.1909) trend for Trial 11 to have consistently higher Δ.

Mean Weighted Skin Temperature, Trial 10,11 (to 40 min, n=8) no Figure.

Trial x Time NS ($p=0.1087$)

Heart Rate, Garment Trials 10,11 (to 40 min, n=8) Figure 52.

Trial x Time NS ($p=0.8603$)

ΔT_{re}, Garment Trials 12,13 (to 40 min, n=7) Figure 53.

Trial x Time NS ($p=0.0776$)

Mean Weighted Skin Temperature, Garment Trials 12,13 (to 40 min, n=6) no Figure.
Trial x Time NS ($p=0.9780$)

Heart Rate, Garment Trials 12,13 (to 40 min, n=7) Figure 54.
Trial x Time NS ($p=0.5223$)

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